US012222128B2

(12) United States Patent
Vandyke et al.

(10) Patent No.: US 12,222,128 B2
(45) Date of Patent: Feb. 11, 2025

(54) **SOUND ABSORBING DUCT FOR ENVIRONMENTAL CONTROL SYSTEM**

(71) Applicant: **THE BOEING COMPANY**, Arlington, VA (US)

(72) Inventors: **Bryce A. Vandyke**, Snohomish, WA (US); **John Erik West**, Seattle, WA (US); **Douglas D. Maben**, Snohomish, WA (US); **Andrew K. Fung**, Everett, WA (US); **David R. C. Cannal**, Marysville, WA (US)

(73) Assignee: **The Boeing Company**, Arlington, VA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **18/346,447**

(22) Filed: **Jul. 3, 2023**

(65) **Prior Publication Data**

US 2023/0358433 A1 Nov. 9, 2023

Related U.S. Application Data

(62) Division of application No. 16/105,864, filed on Aug. 20, 2018, now Pat. No. 11,739,973.

(51) **Int. Cl.**

F24F 13/02	(2006.01)
B64D 13/06	(2006.01)
F24F 13/24	(2006.01)

(52) **U.S. Cl.**

CPC .. ***F24F 13/0263*** (2013.01); *B64D 2013/0603* (2013.01); *F24F 13/0245* (2013.01); *F24F 13/0281* (2013.01); *F24F 2013/242* (2013.01)

(58) **Field of Classification Search**

CPC B64D 2033/0206; B32B 2307/304; B32B 2307/102; B32B 2605/18; B32B 3/12; B32B 3/266; B32B 1/08; B32B 2597/00; B32B 5/024; B32B 5/245; F24F 13/0263; F24F 2013/242; F24F 13/24; F24F 13/0245; F24F 13/0281; B29L 2009/00;

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,400,863 A *	8/1983	Schroeder	B29C 53/587	138/120
5,785,091 A *	7/1998	Barker, II	F16L 59/143	138/123

(Continued)

FOREIGN PATENT DOCUMENTS

CN	2773455 Y	4/2006
CN	107327650 A	11/2017

(Continued)

OTHER PUBLICATIONS

Extended European Search Report, Application No. 19192673.2, Dated Nov. 6, 2019, 7 Pages.

(Continued)

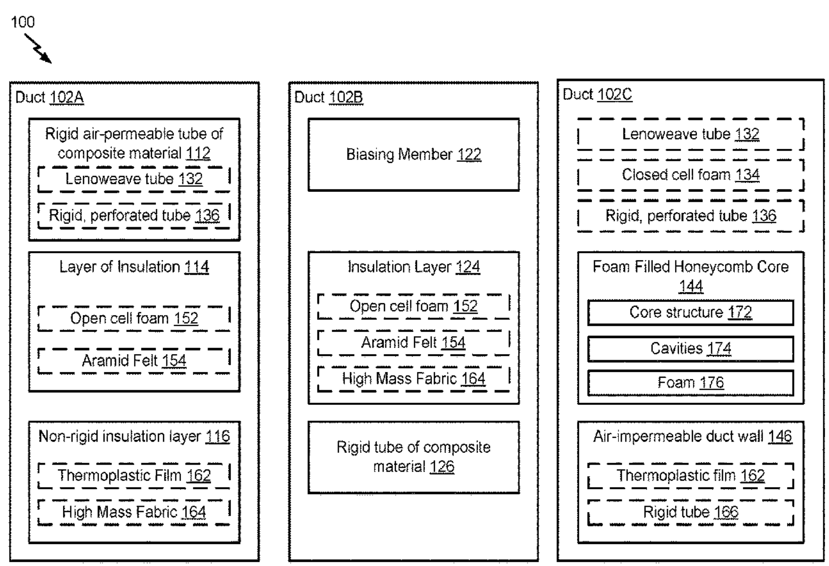
Primary Examiner — Vivek K Shirsat

(74) *Attorney, Agent, or Firm* — Kunzler Bean & Adamson

(57) **ABSTRACT**

A duct includes a rigid air-permeable tube of composite material. The duct also includes a layer of insulation coupled to an exterior surface of the rigid air-permeable tube. The duct further includes a non-rigid insulation layer in contact with the layer of insulation. The non-rigid insulation layer forms an air-impermeable duct wall.

24 Claims, 19 Drawing Sheets



(58) **Field of Classification Search**
CPC . F01N 1/24; F01N 13/14; F01N 13/16; F01N 2510/04; F16L 55/0336; F16L 9/21; Y10T 156/1031; Y10T 428/23; Y10T 428/24149; Y10T 428/24157; Y10T 428/249953; Y10T 428/31504
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,947,158	A	9/1999	Gross et al.	
7,842,147	B2	11/2010	Shen et al.	
8,371,338	B2	2/2013	Princell et al.	
8,393,436	B2 *	3/2013	Tomerlin	F01N 1/24 138/129
8,789,650	B2	7/2014	West	
8,899,377	B2	12/2014	Thomas	
9,567,087	B1	2/2017	Monacchio et al.	
9,896,216	B2	2/2018	Linert et al.	
2007/0074930	A1	4/2007	Tomerlin et al.	
2007/0131299	A1	6/2007	Kornbleet	
2009/0200103	A1	8/2009	Potschka	
2010/0018601	A1 *	1/2010	Princell	F16L 59/147 138/149
2010/0044149	A1	2/2010	Patel et al.	
2010/0071289	A1	3/2010	Princell et al.	
2010/0209679	A1 *	8/2010	Tompkins	B64C 1/40 428/220
2011/0139289	A1	6/2011	Qi	
2012/0261211	A1	10/2012	Tomerlin et al.	
2012/0267476	A1	10/2012	Thomas	
2013/0122244	A1	5/2013	Patel et al.	
2018/0017200	A1 *	1/2018	Keough	B32B 3/28
2019/0270504	A1	9/2019	Cedar et al.	
2020/0056727	A1	2/2020	Maben et al.	
2020/0056803	A1	2/2020	Vandyke et al.	
2020/0190278	A1	6/2020	Gardner et al.	

FOREIGN PATENT DOCUMENTS

WO	2006045723	A1	5/2006
WO	2010149353	A1	12/2010

OTHER PUBLICATIONS

Extended European Search Report, Application No. 19192686.4, Dated Nov. 6, 2019, 8 Pages.
https://www.youtube.com/watch?v=KcpXUKp9yOQ.
Communication Pursuant To Article 94(3) EPC for Application No. 19192673.2, Dated Dec. 8, 2020, 4 Pages.
1st Chinese Office Action Received for Application No. 201910663591.3, Maled Mar. 16, 2020, 13 Pages.

* cited by examiner

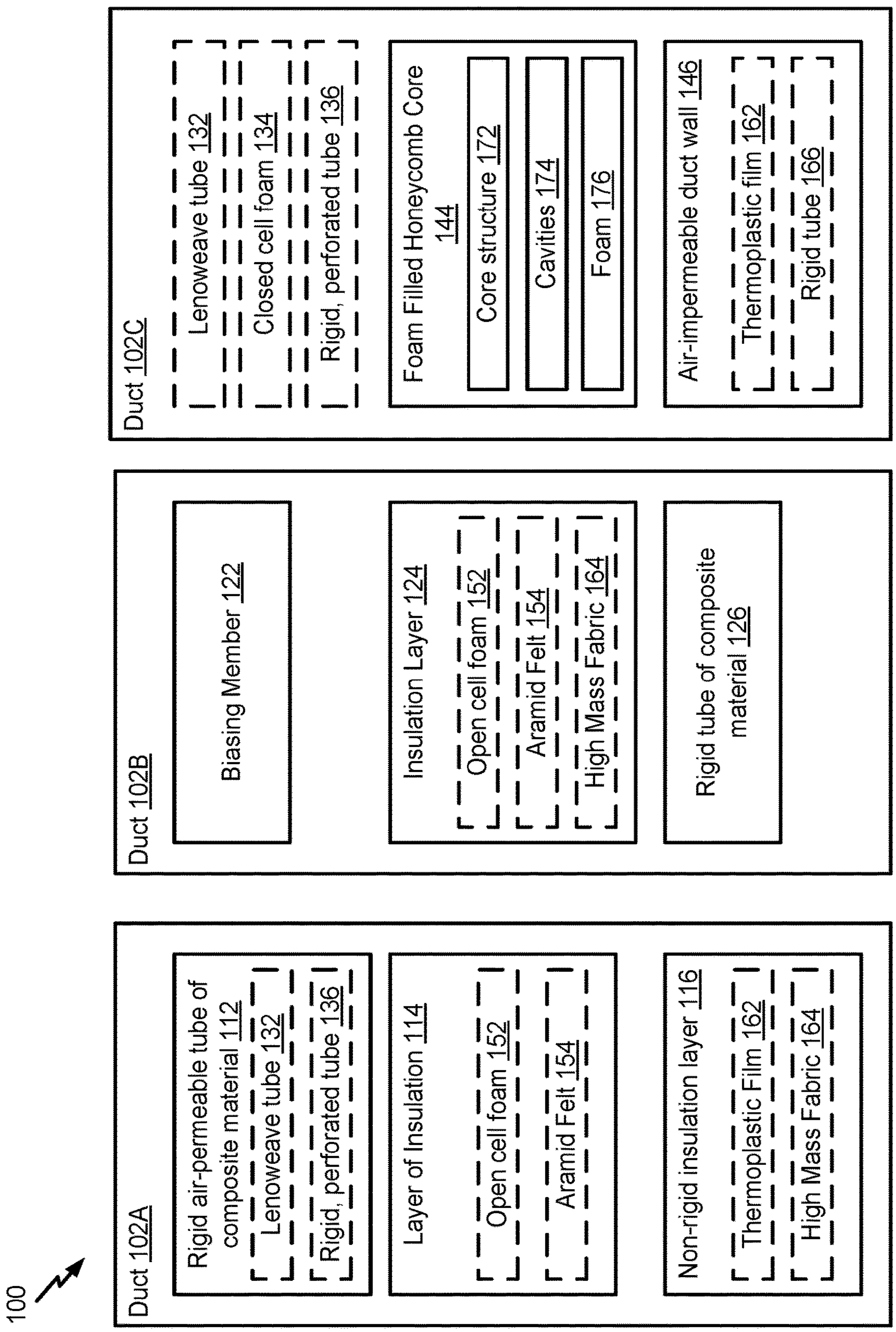

100
Duct 102A
Rigid air-permeable tube of composite material 112
Lenoweave tube 132
Rigid, perforated tube 136
Layer of Insulation 114
Open cell foam 152
Aramid Felt 154
Non-rigid insulation layer 116
Thermoplastic Film 162
High Mass Fabric 164
Duct 102B
Biasing Member 122
Insulation Layer 124
Open cell foam 152
Aramid Felt 154
High Mass Fabric 164
Rigid tube of composite material 126
Duct 102C
Lenoweave tube 132
Closed cell foam 134
Rigid, perforated tube 136
Foam Filled Honeycomb Core 144
Core structure 172
Cavities 174
Foam 176
Air-impermeable duct wall 146
Thermoplastic film 162
Rigid tube 166

FIG. 1

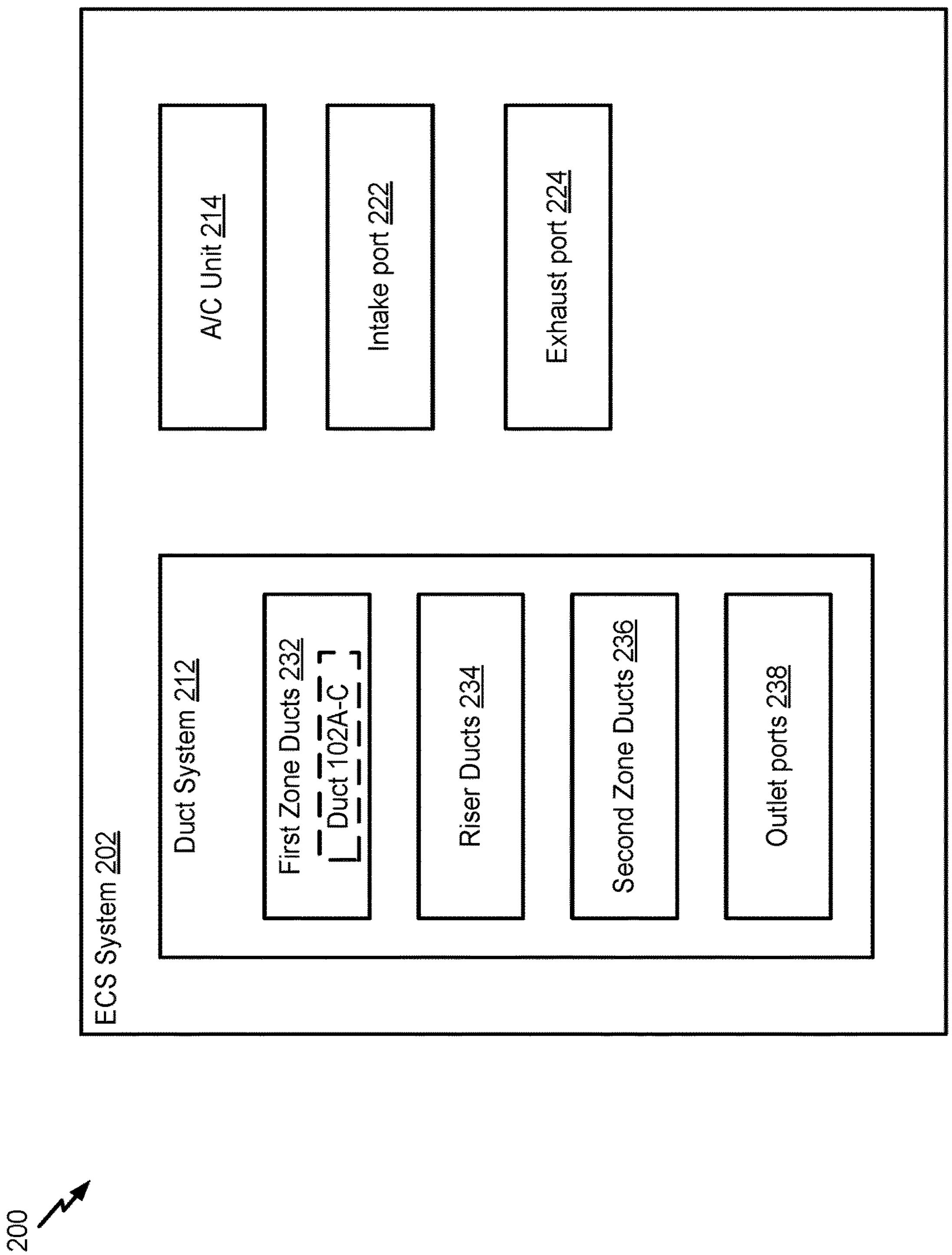

ECS System 202
Duct System 212
First Zone Ducts 232
Duct 102A-C
Riser Ducts 234
Second Zone Ducts 236
Outlet ports 238
A/C Unit 214
Intake port 222
Exhaust port 224
200

FIG. 2

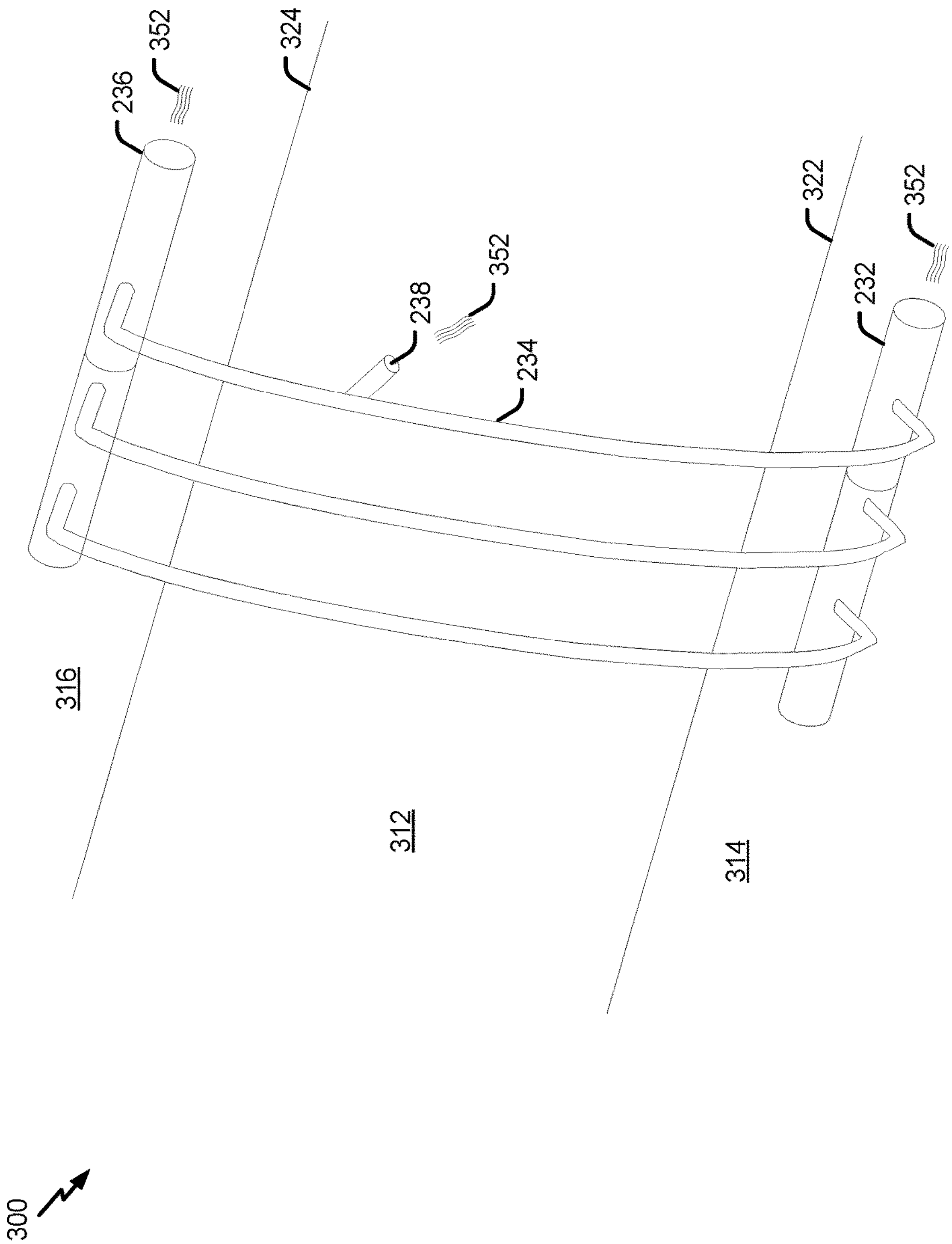


FIG. 3

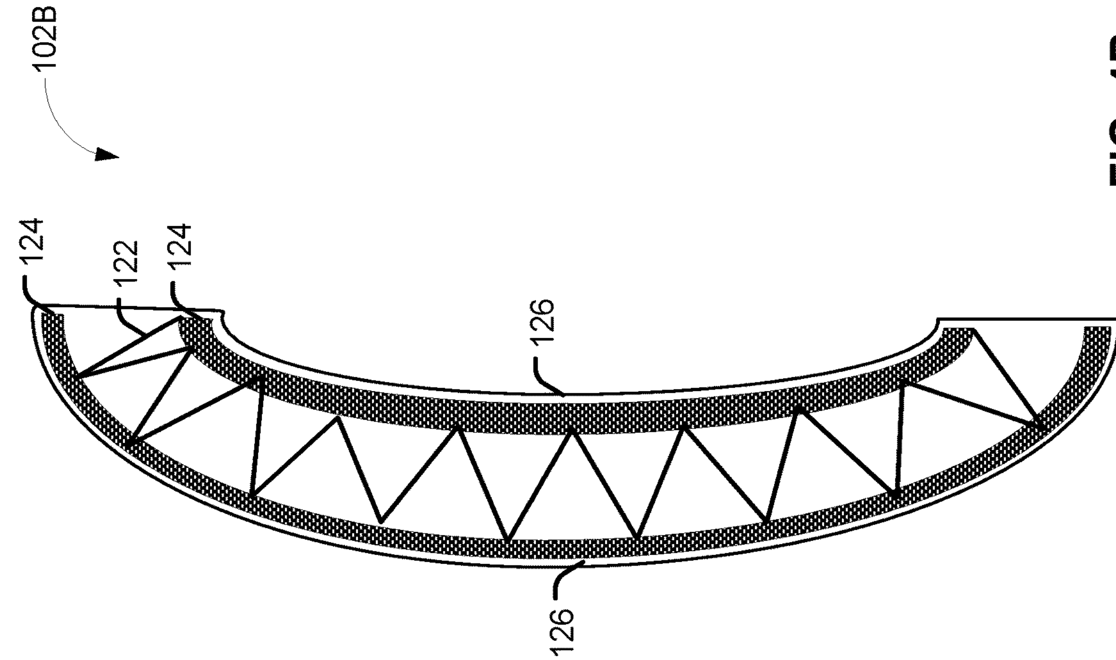


FIG. 4B

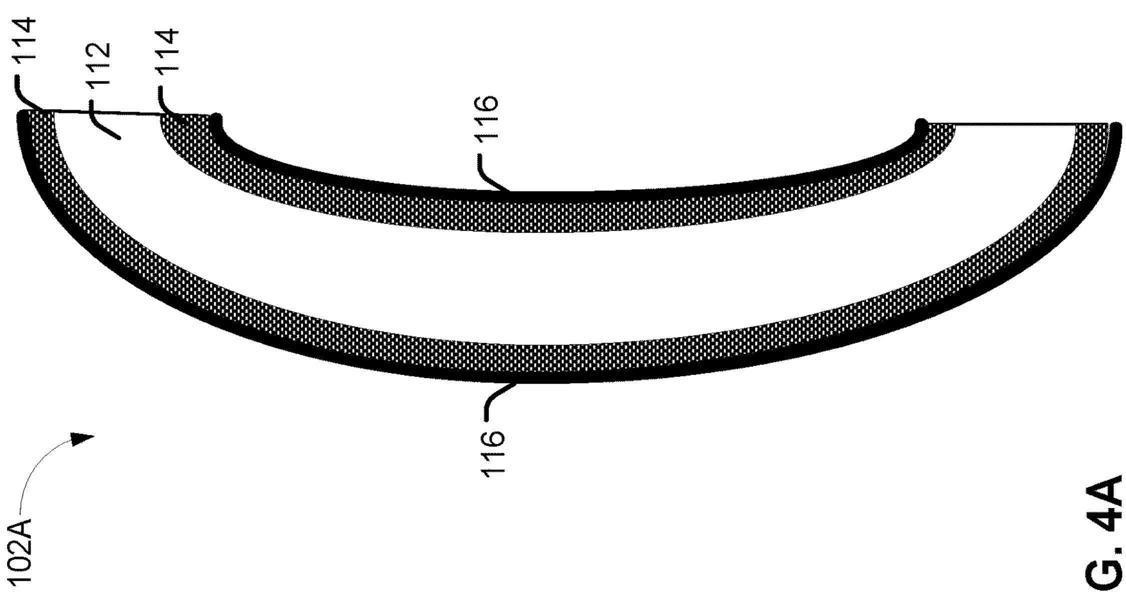


FIG. 4A

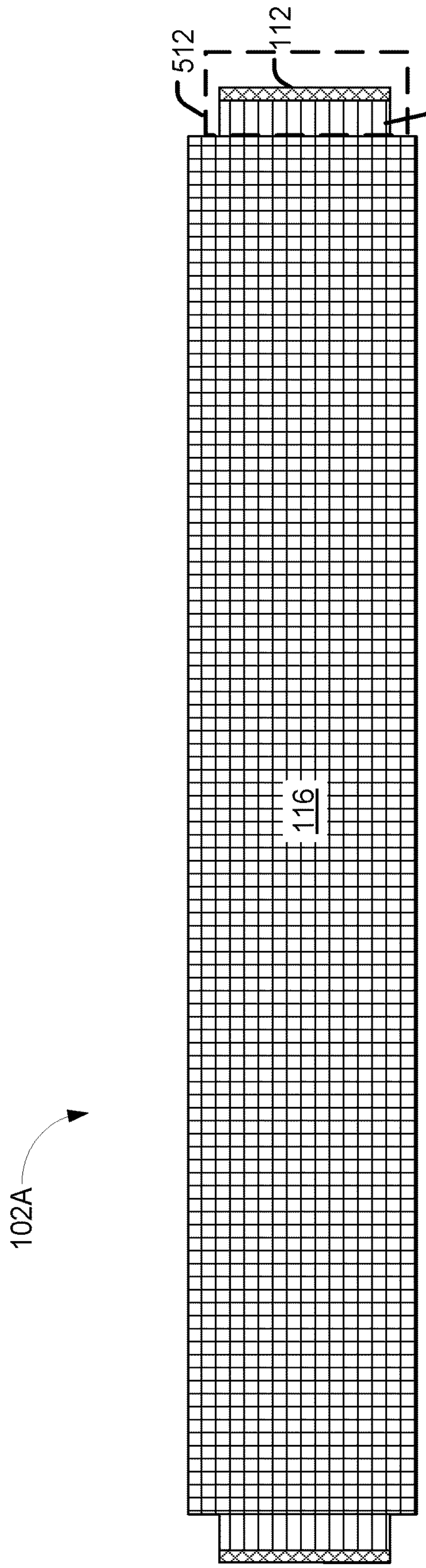


FIG. 5A

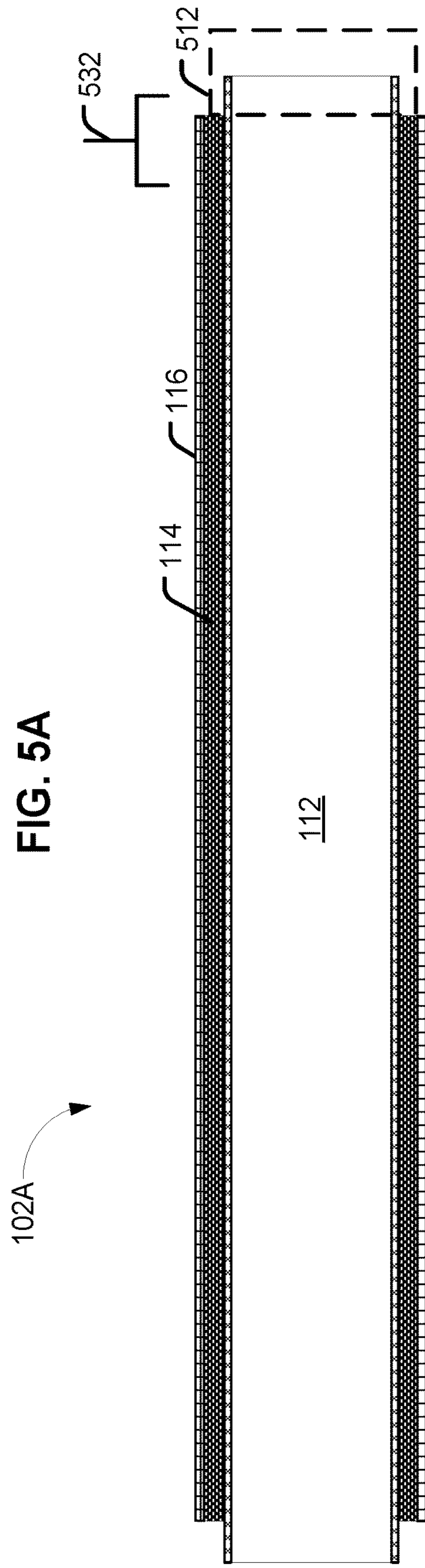


FIG. 5B

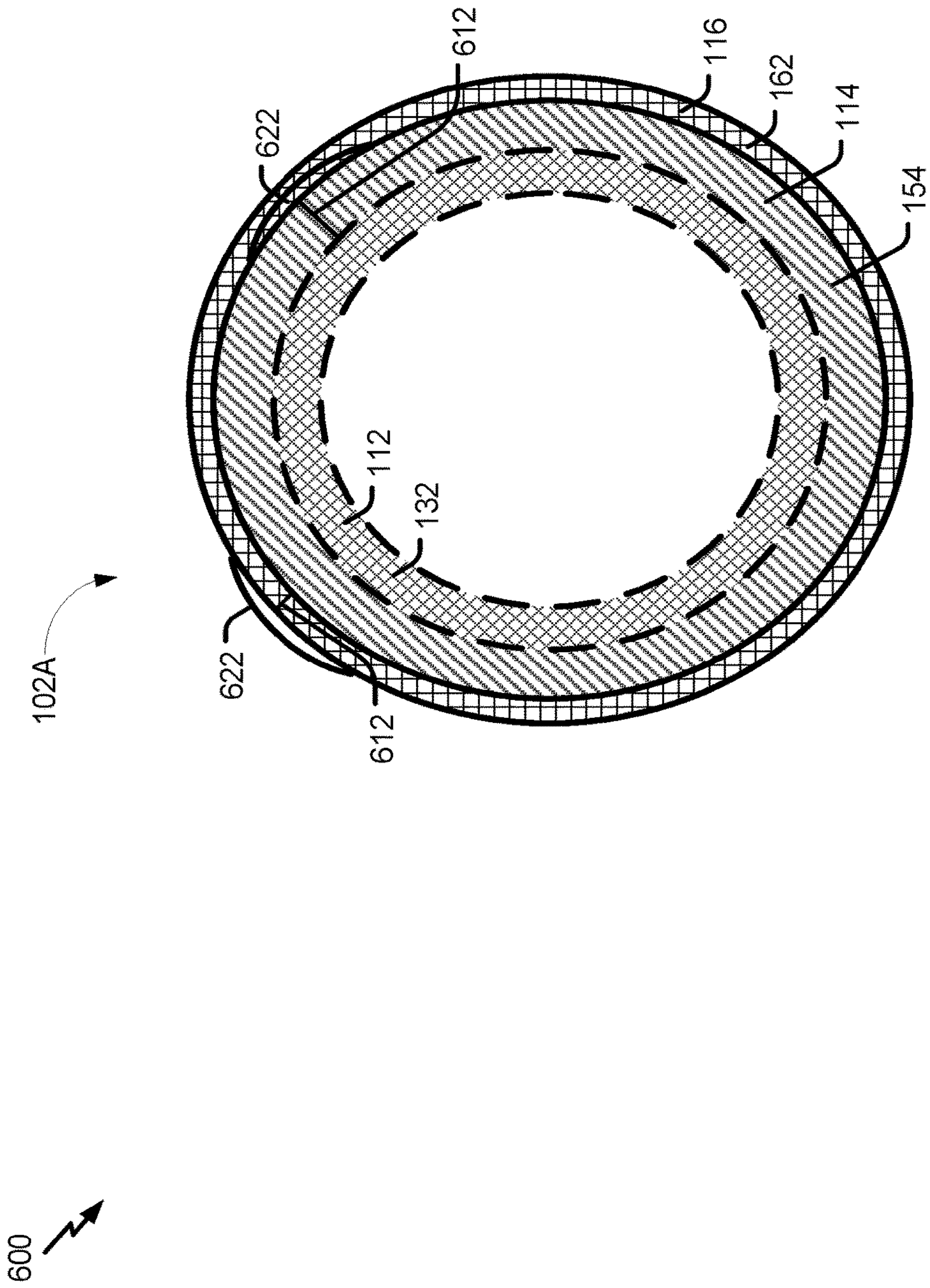


FIG. 6

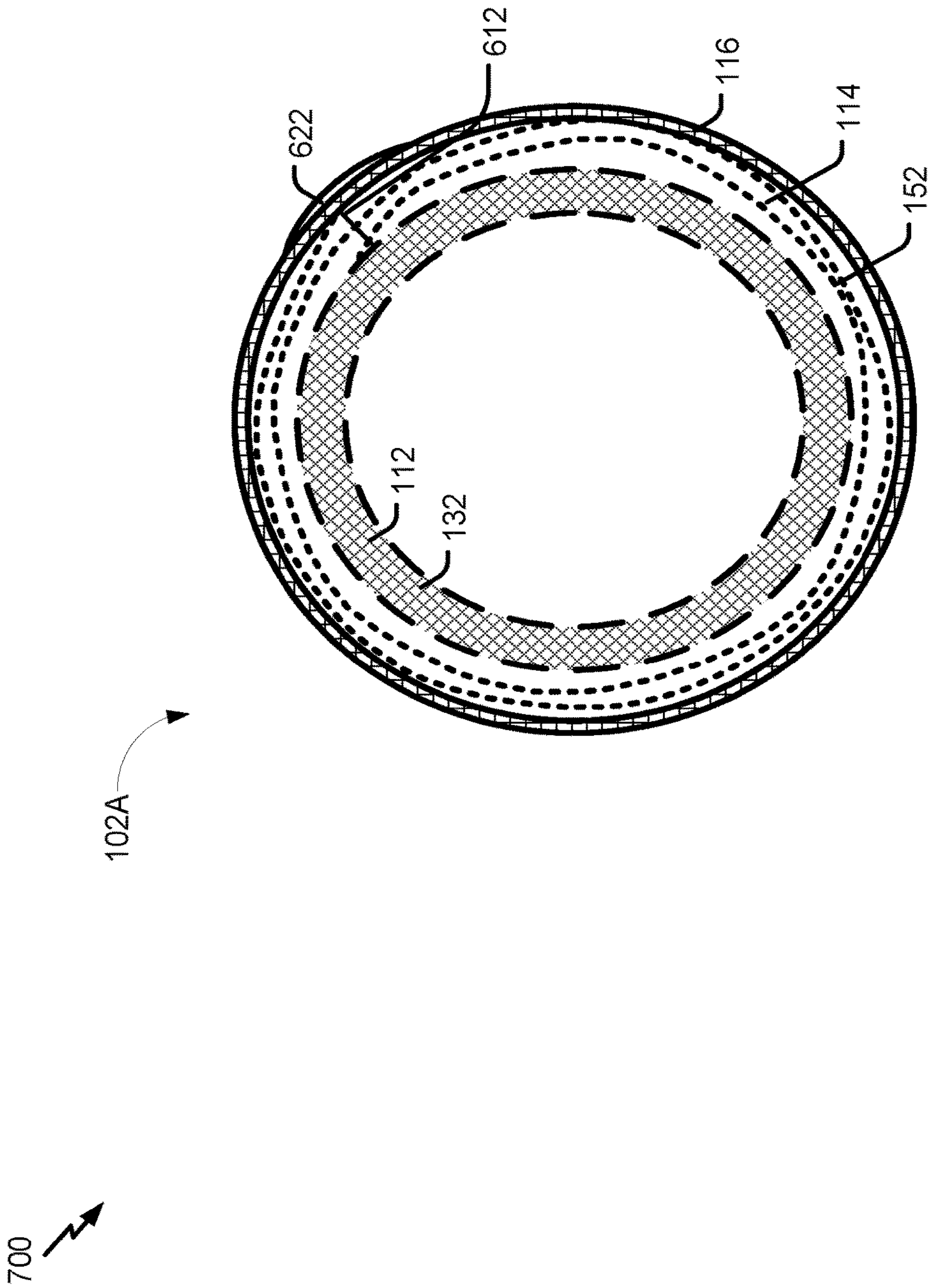


FIG. 7

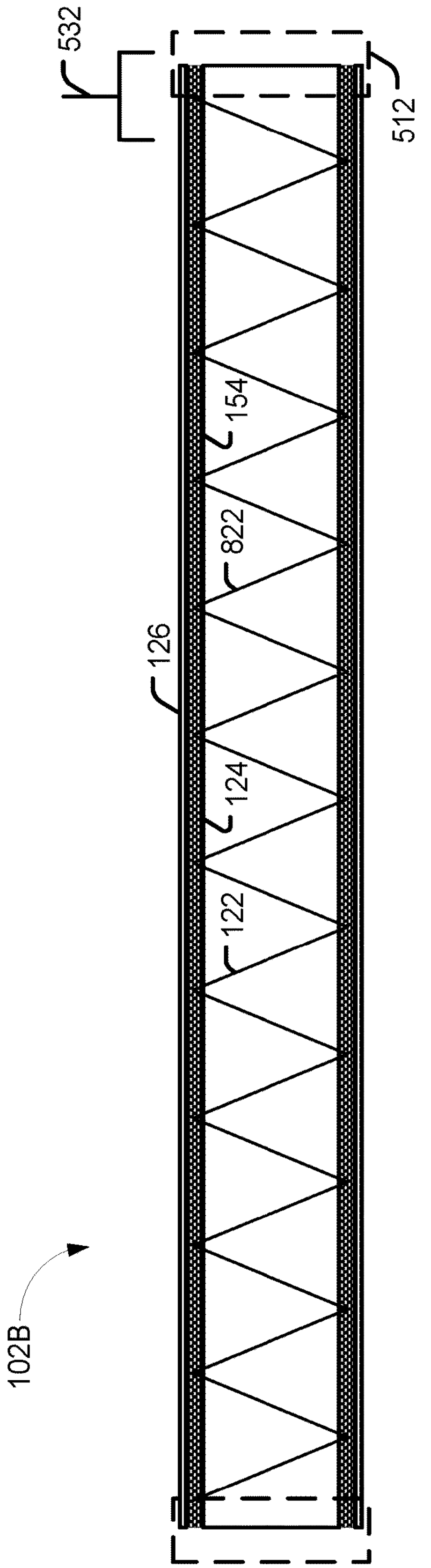

532
512
154
822
126
124
122
102B

FIG. 8A

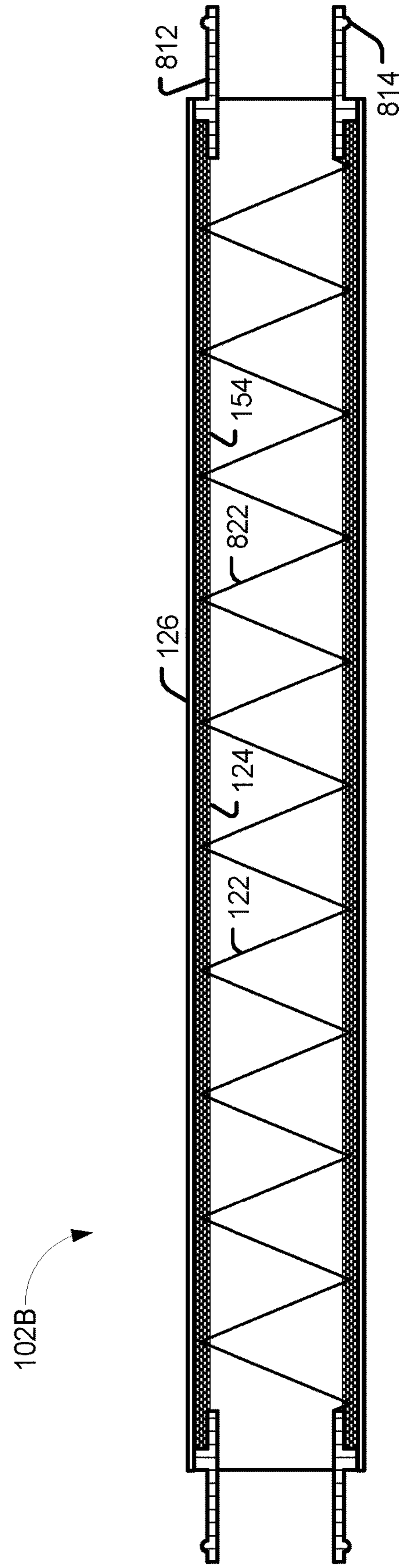

812
814
154
822
126
124
122
102B

FIG. 8B

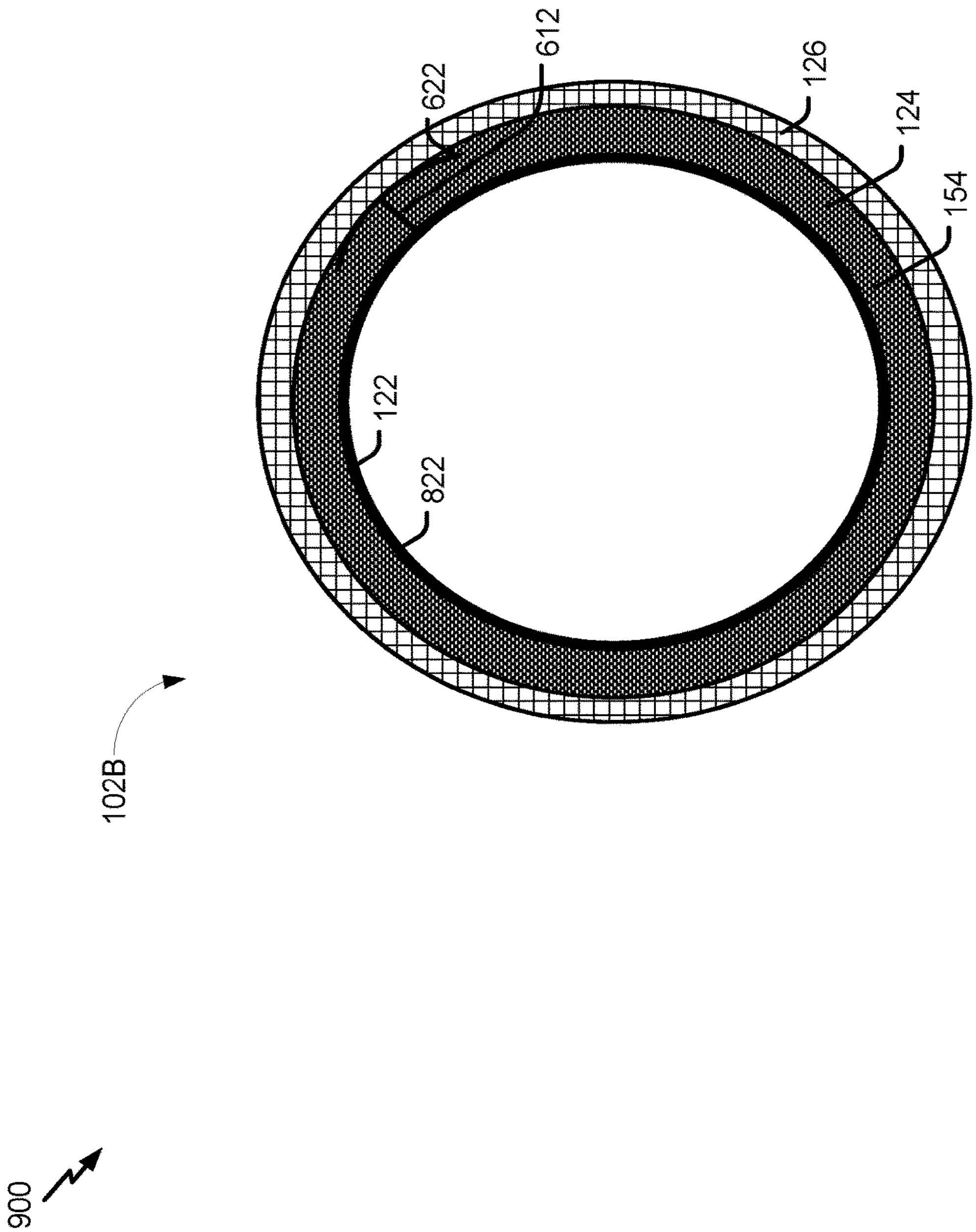


FIG. 9

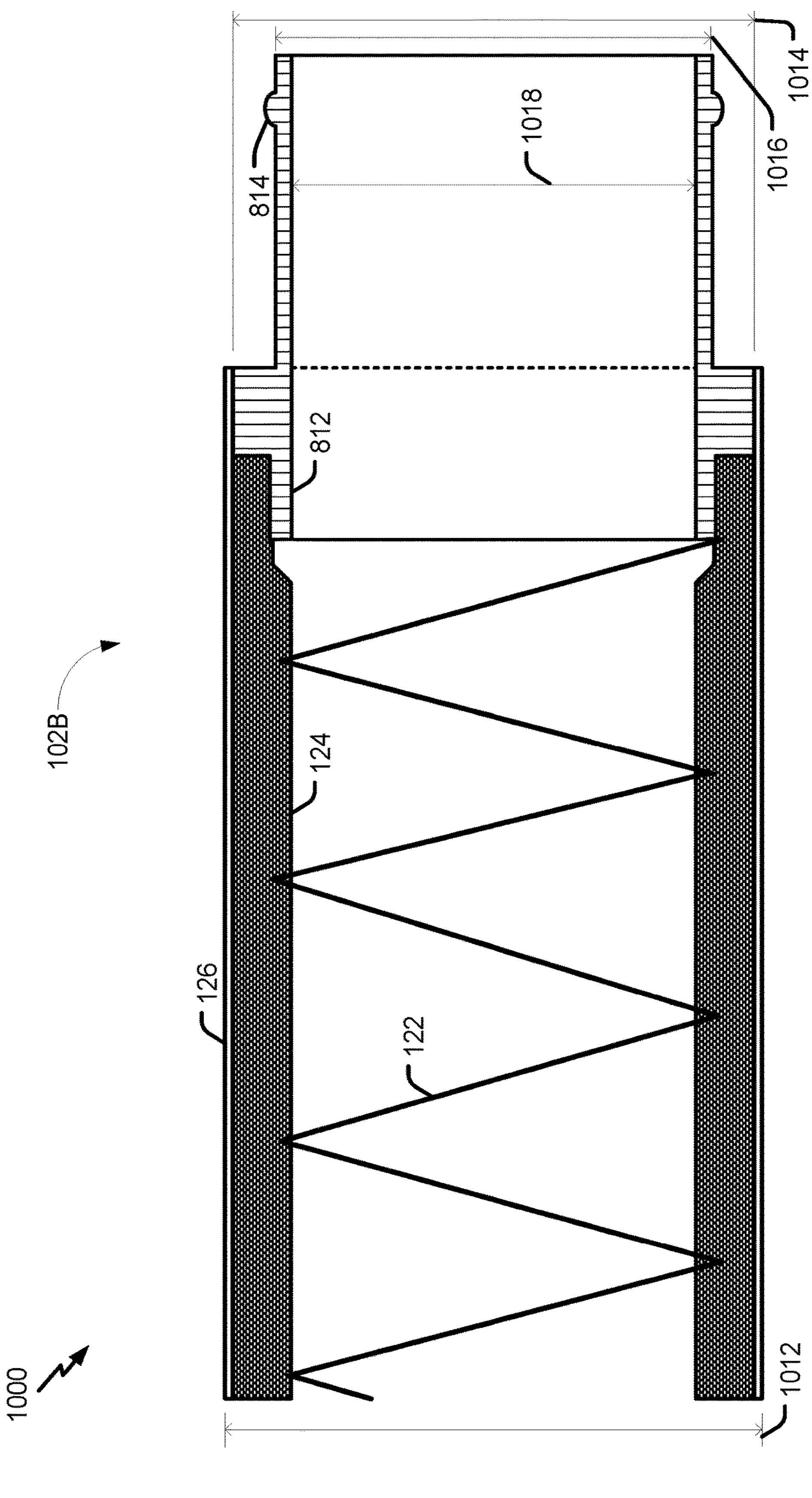


FIG. 10

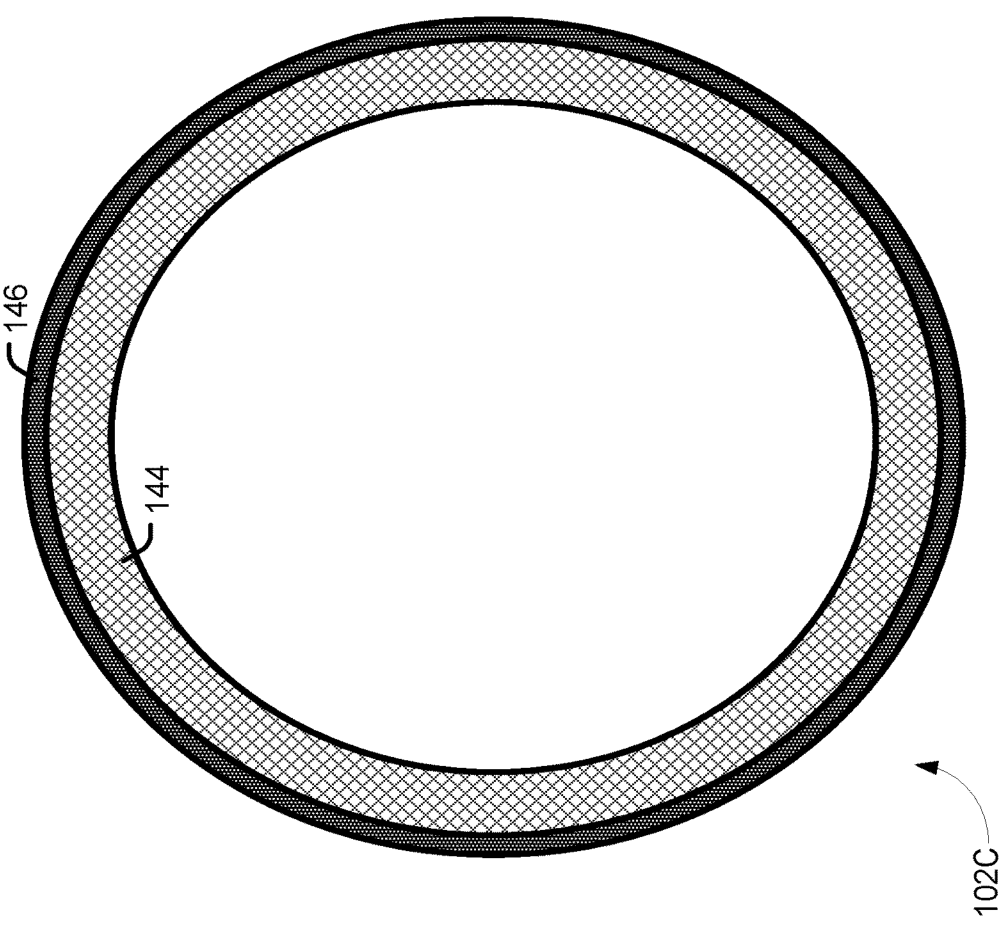


FIG. 11A

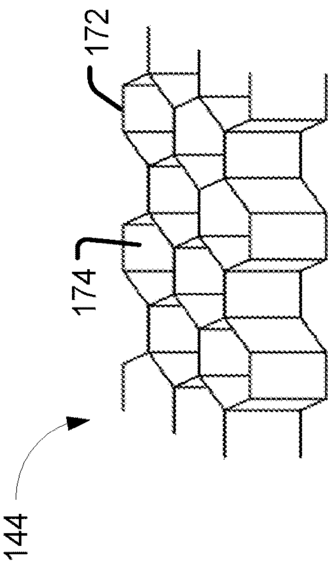


FIG. 11B

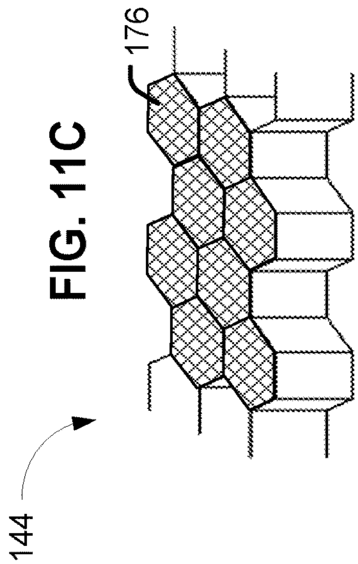


FIG. 11C

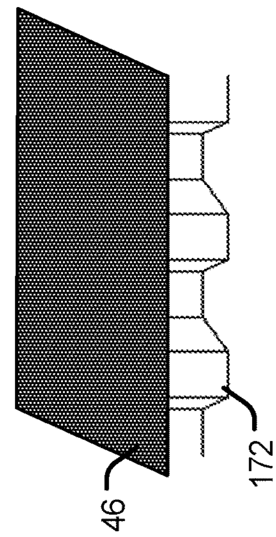


FIG. 11D

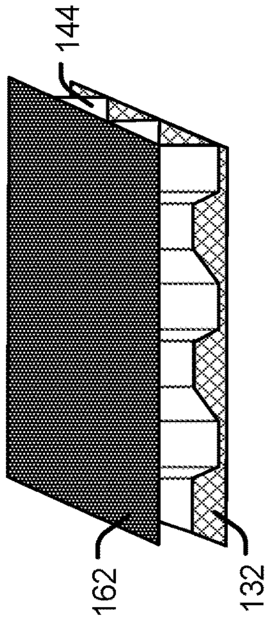


FIG. 12B

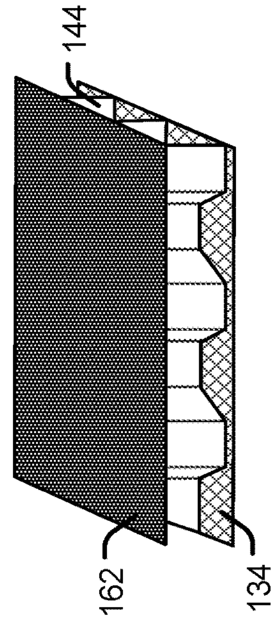


FIG. 12C

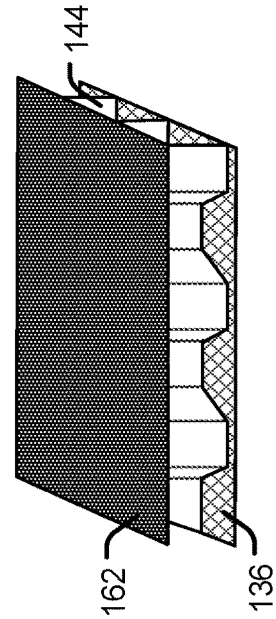


FIG. 12D

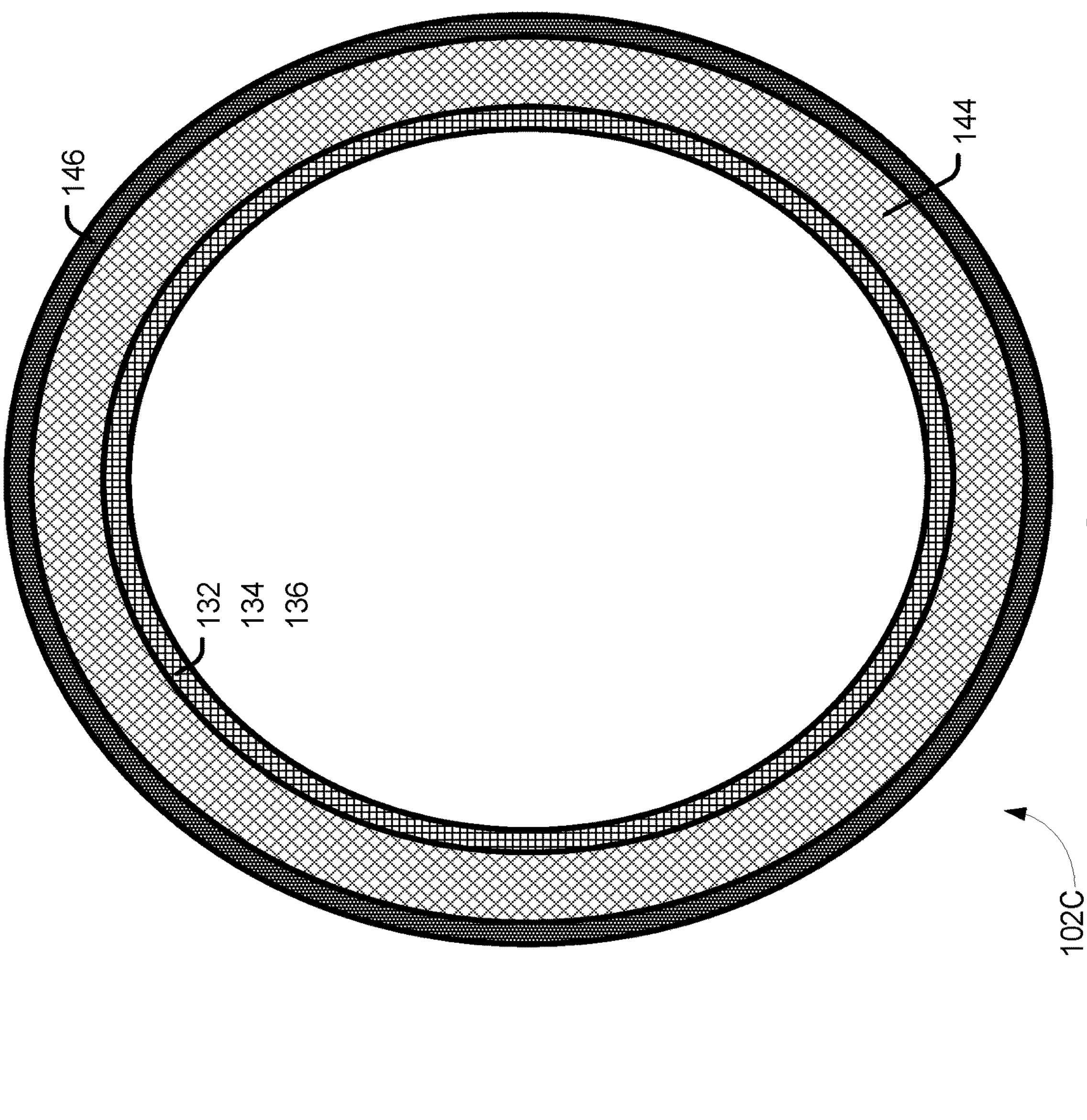


FIG. 12A

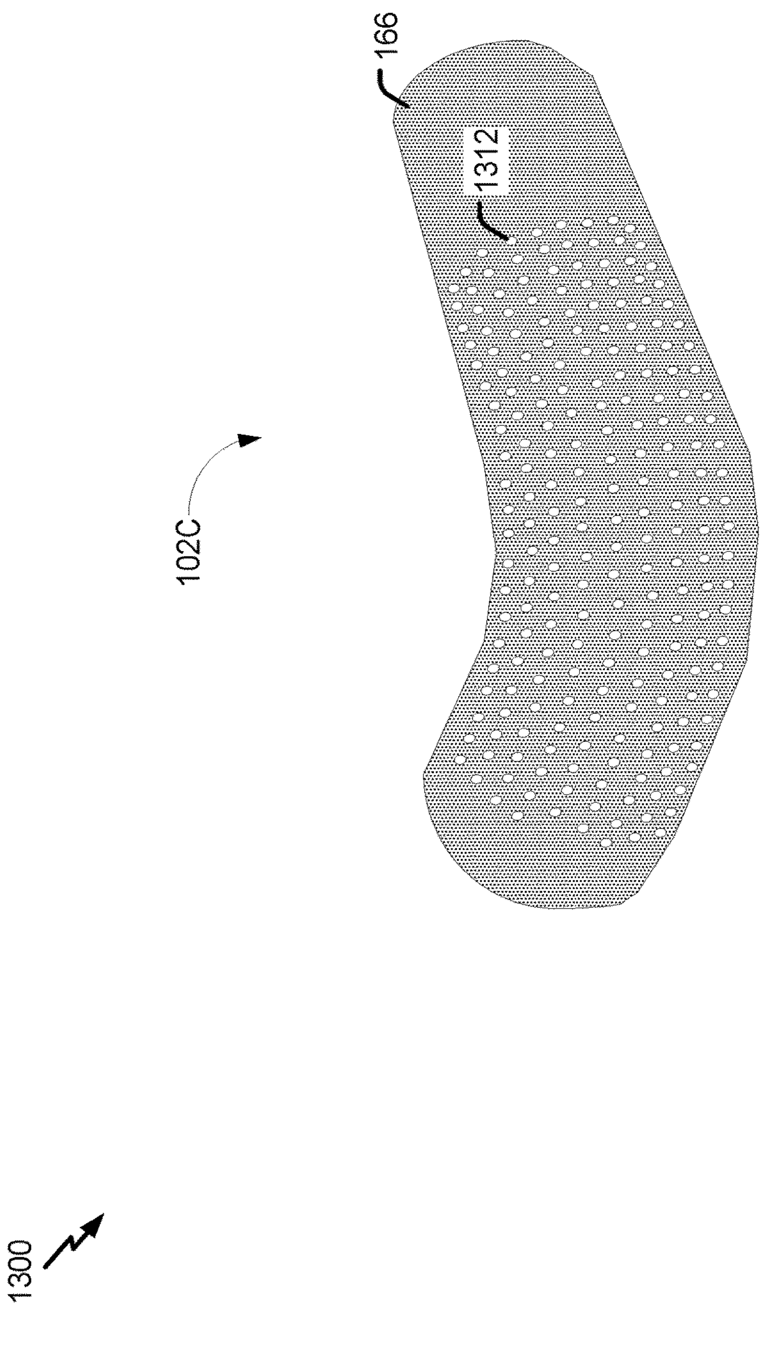


FIG. 13

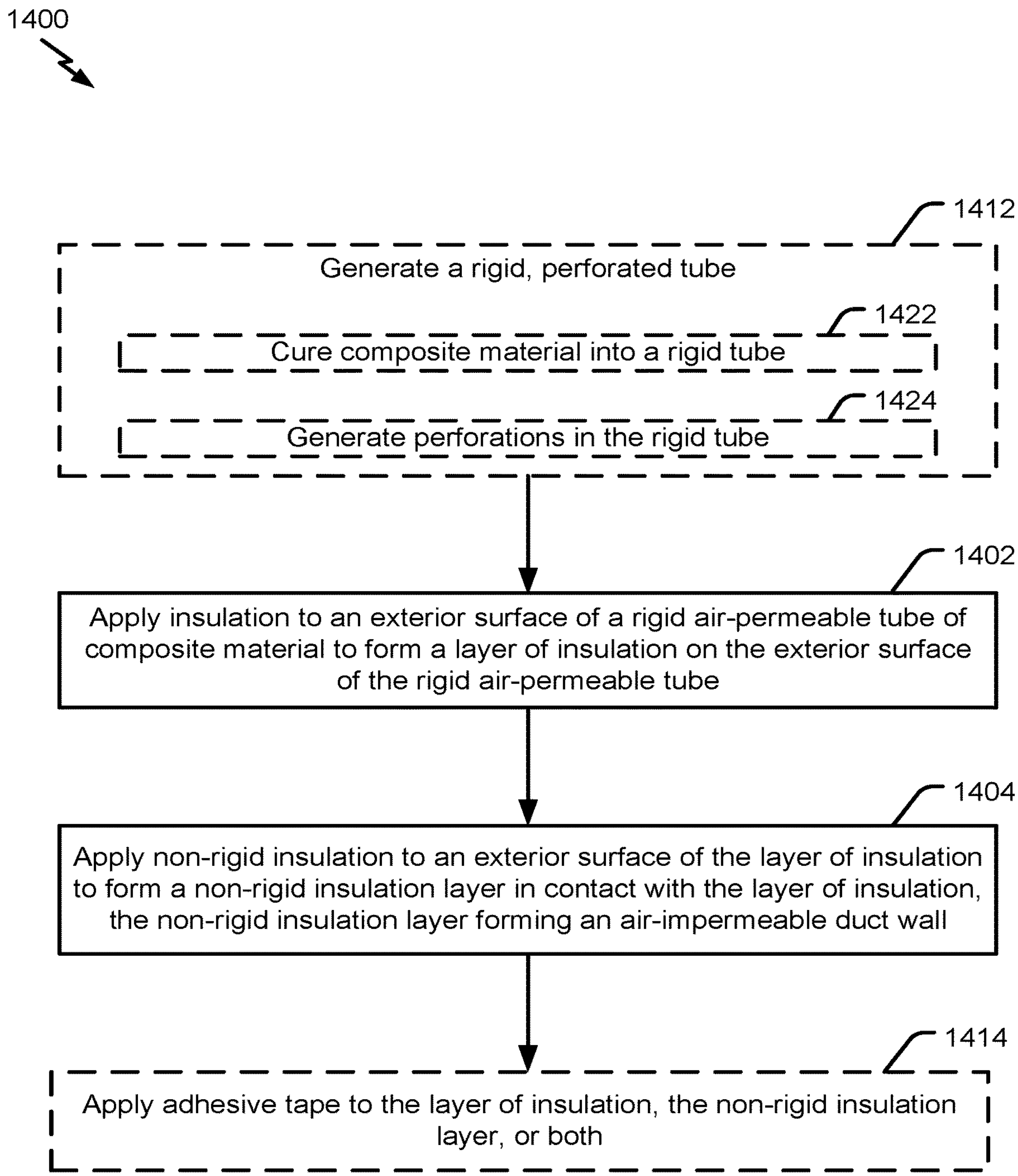

1400
1412
Generate a rigid, perforated tube
1422
Cure composite material into a rigid tube
1424
Generate perforations in the rigid tube
1402
Apply insulation to an exterior surface of a rigid air-permeable tube of composite material to form a layer of insulation on the exterior surface of the rigid air-permeable tube
1404
Apply non-rigid insulation to an exterior surface of the layer of insulation to form a non-rigid insulation layer in contact with the layer of insulation, the non-rigid insulation layer forming an air-impermeable duct wall
1414
Apply adhesive tape to the layer of insulation, the non-rigid insulation layer, or both

FIG. 14

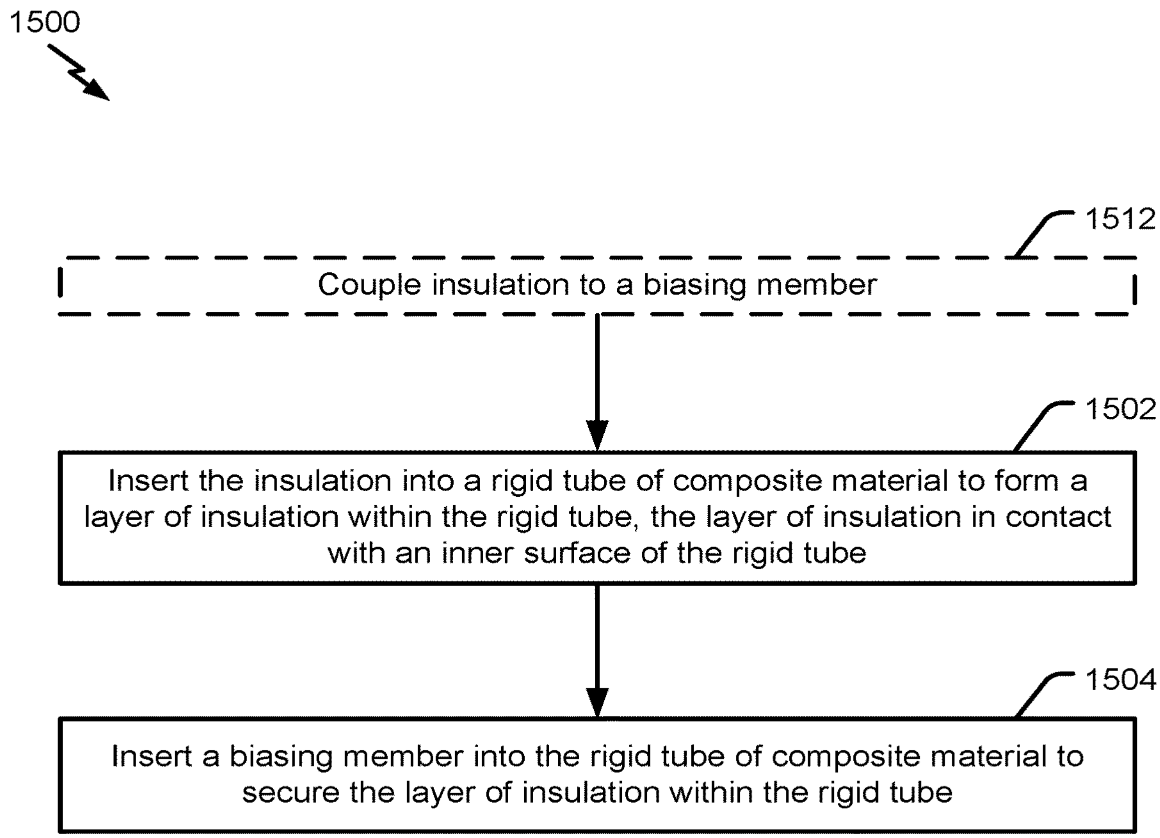

1500
1512
Couple insulation to a biasing member
1502
Insert the insulation into a rigid tube of composite material to form a layer of insulation within the rigid tube, the layer of insulation in contact with an inner surface of the rigid tube
1504
Insert a biasing member into the rigid tube of composite material to secure the layer of insulation within the rigid tube

FIG. 15

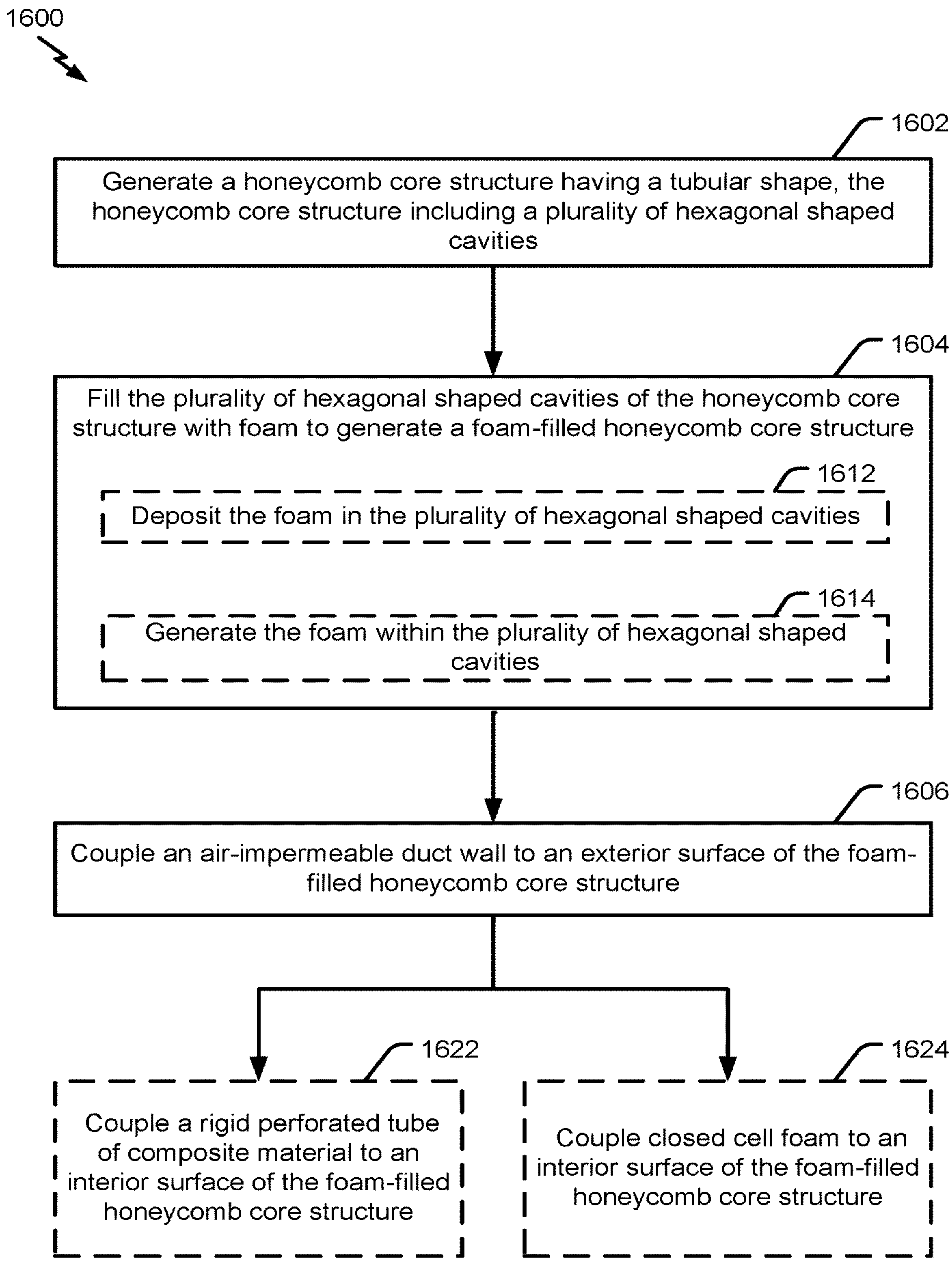

1600
1602
Generate a honeycomb core structure having a tubular shape, the honeycomb core structure including a plurality of hexagonal shaped cavities
1604
Fill the plurality of hexagonal shaped cavities of the honeycomb core structure with foam to generate a foam-filled honeycomb core structure
1612
Deposit the foam in the plurality of hexagonal shaped cavities
1614
Generate the foam within the plurality of hexagonal shaped cavities
1606
Couple an air-impermeable duct wall to an exterior surface of the foam-filled honeycomb core structure
1622
Couple a rigid perforated tube of composite material to an interior surface of the foam-filled honeycomb core structure
1624
Couple closed cell foam to an interior surface of the foam-filled honeycomb core structure

FIG. 16

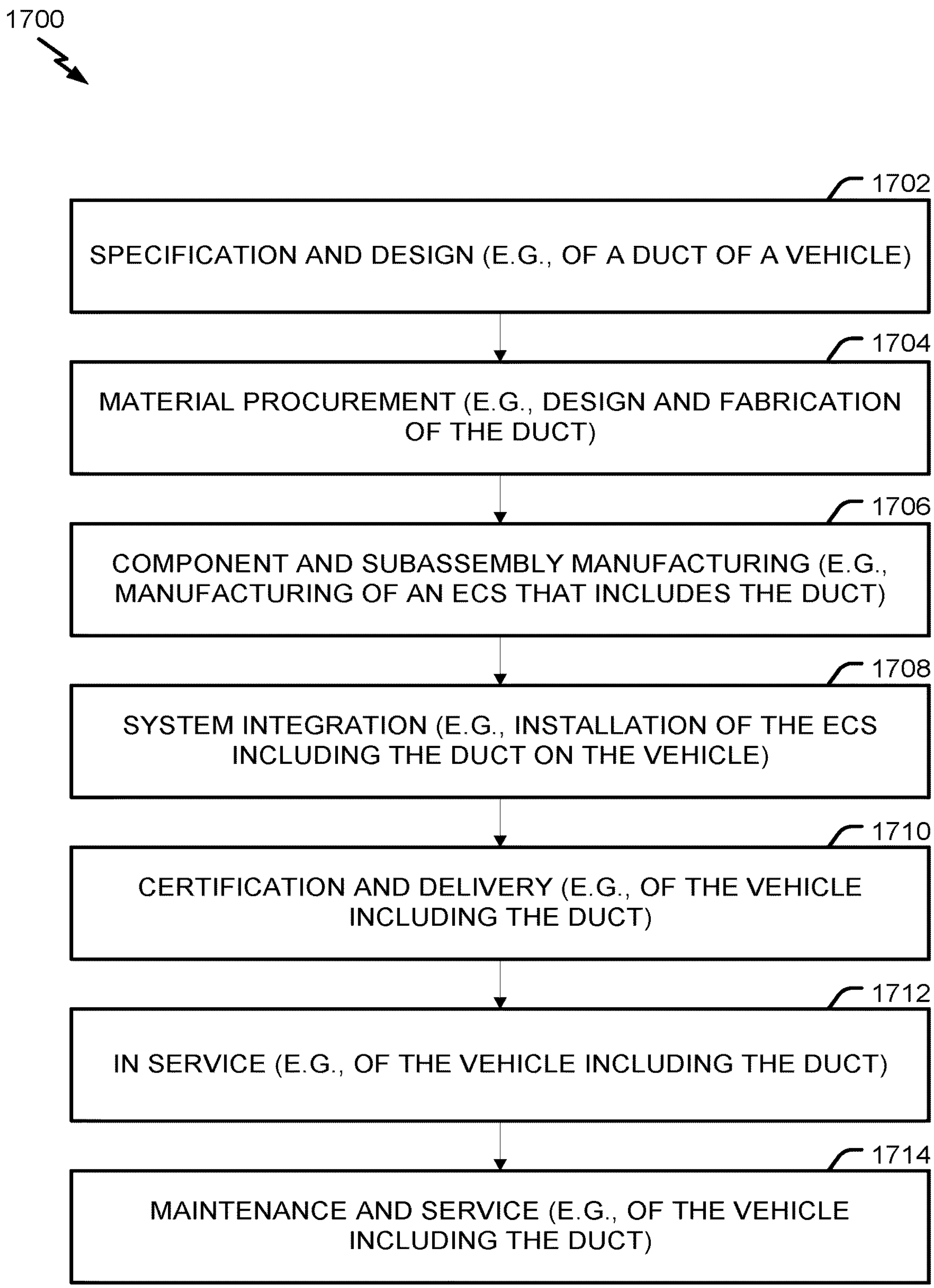

1700
1702
SPECIFICATION AND DESIGN (E.G., OF A DUCT OF A VEHICLE)
1704
MATERIAL PROCUREMENT (E.G., DESIGN AND FABRICATION OF THE DUCT)
1706
COMPONENT AND SUBASSEMBLY MANUFACTURING (E.G., MANUFACTURING OF AN ECS THAT INCLUDES THE DUCT)
1708
SYSTEM INTEGRATION (E.G., INSTALLATION OF THE ECS INCLUDING THE DUCT ON THE VEHICLE)
1710
CERTIFICATION AND DELIVERY (E.G., OF THE VEHICLE INCLUDING THE DUCT)
1712
IN SERVICE (E.G., OF THE VEHICLE INCLUDING THE DUCT)
1714
MAINTENANCE AND SERVICE (E.G., OF THE VEHICLE INCLUDING THE DUCT)

FIG. 17

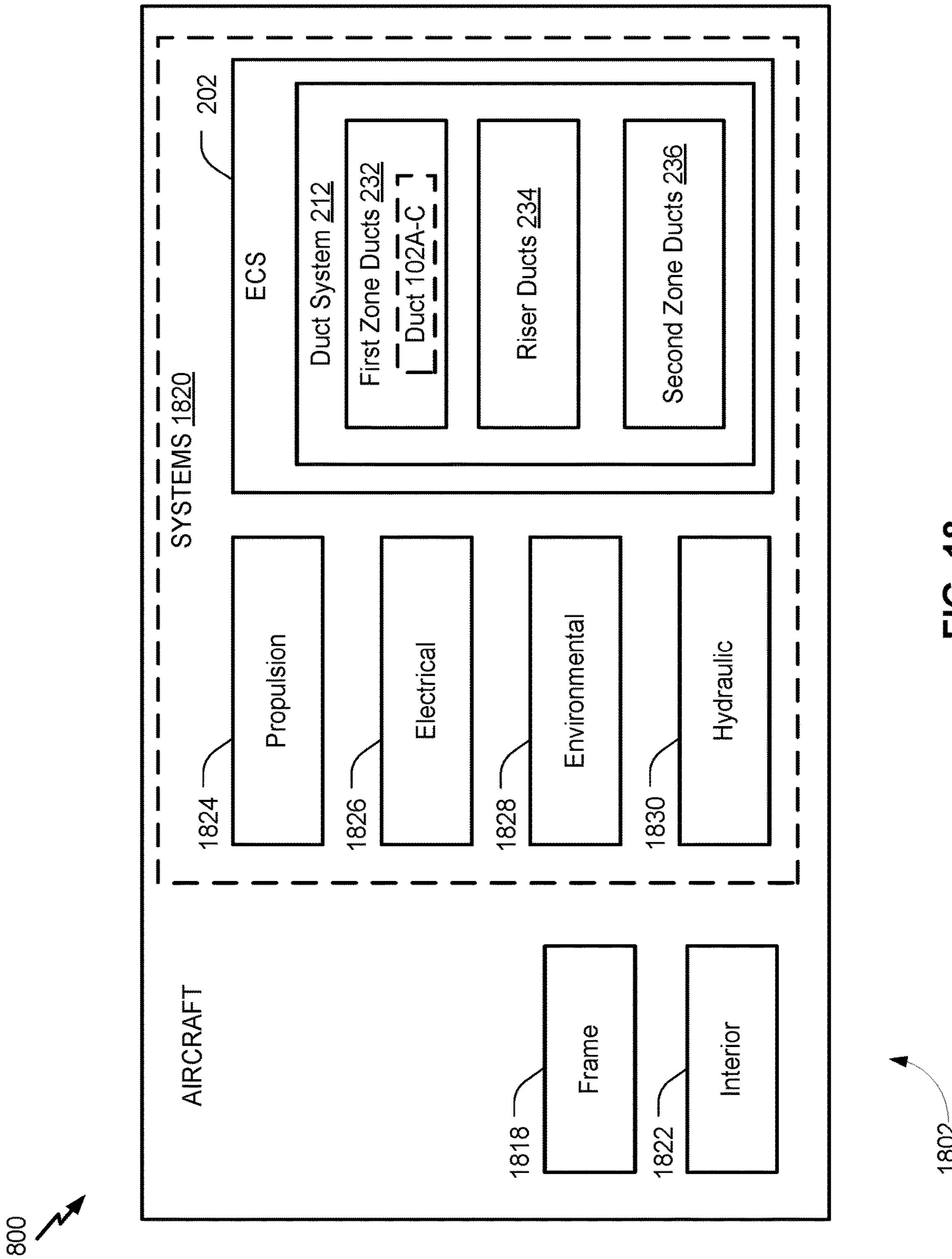

1800
AIRCRAFT
1802
SYSTEMS 1820
202
ECS
Duct System 212
First Zone Ducts 232
Duct 102A-C
Riser Ducts 234
Second Zone Ducts 236
1824
Propulsion
1826
Electrical
1828
Environmental
1830
Hydraulic
1818
Frame
1822
Interior

FIG. 18

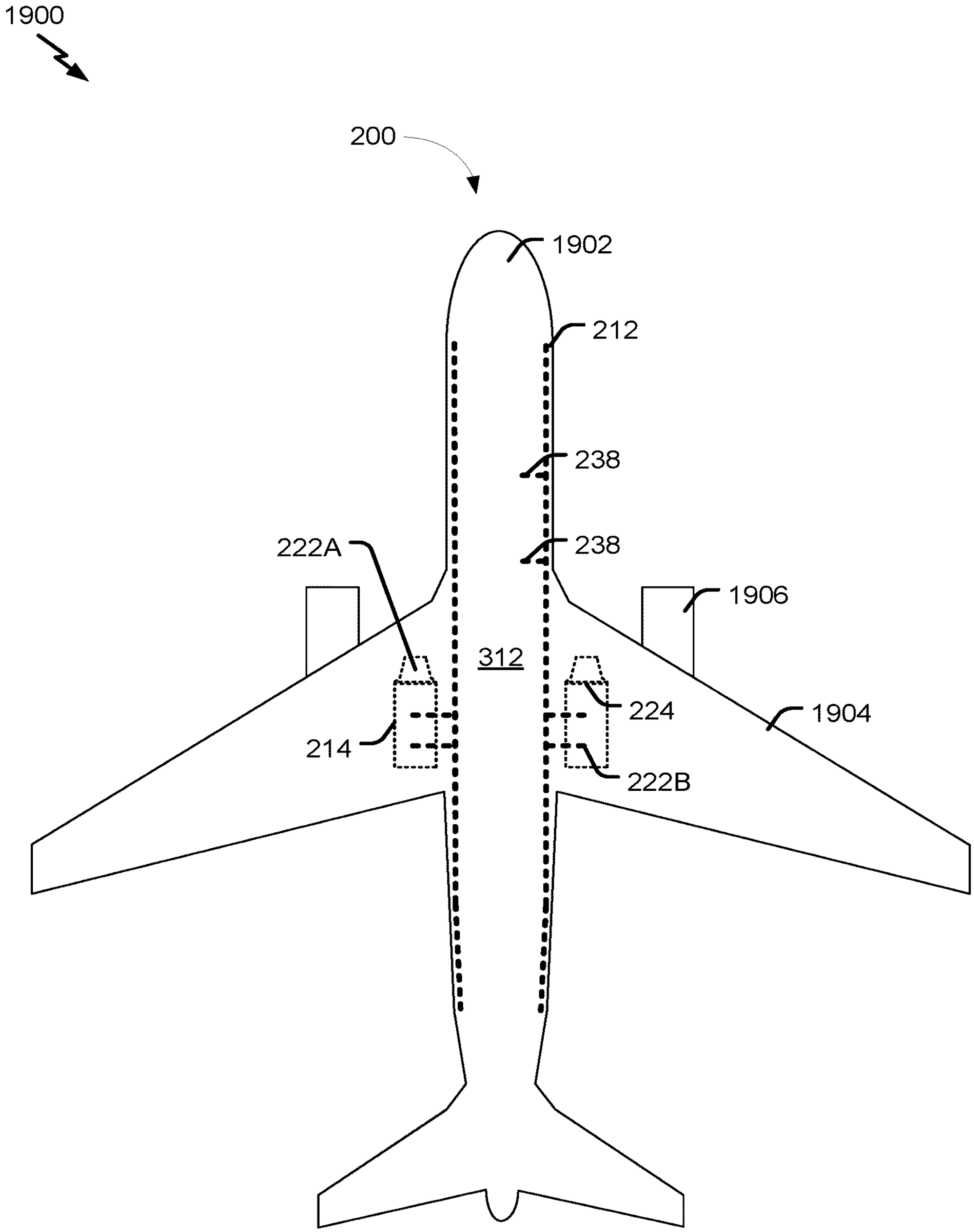


FIG. 19

SOUND ABSORBING DUCT FOR ENVIRONMENTAL CONTROL SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Divisional of and claims the benefit of and priority to U.S. patent application Ser. No. 16/105,864 filed Aug. 20, 2018, the contents of which are incorporated by reference in its entirety.

FIELD OF THE DISCLOSURE

The present disclosure is generally related to ducts of an environmental control system that absorb sound.

BACKGROUND

Vehicles, such as aircraft, include environmental control systems to provide treated air to passengers, such as conditioned air, filtered air, etc. An environmental control system generally includes ducts to transport the treated air to passengers of the vehicle. The treated air moving within the ducts creates noise, which may decrease passenger comfort. Noise attenuating mufflers (e.g., zone mufflers) are often used to reduce (e.g., absorb) the noise generated by the moving air. For example, a muffler encases a duct of the environmental control system and attenuates noise using insulation and/or chambers. However, noise attenuating mufflers add weight, volume, and cost to environmental control systems. In high performance vehicles, such as aircraft, increased weight and volume increases costs and decreases performance.

SUMMARY

In a particular implementation, a duct includes a rigid air-permeable tube of composite material. The duct also includes a layer of insulation coupled to an exterior surface of the rigid air-permeable tube. The duct further includes a non-rigid insulation layer in contact with the layer of insulation. The non-rigid insulation layer forms an air-impermeable duct wall.

In another particular implementation, a duct includes a rigid tube of composite material. The duct also includes an insulation layer disposed within the rigid tube. The duct further includes a biasing member disposed within the rigid tube. The biasing member is configured to restrain the insulation layer against an interior surface of the rigid tube.

In a particular implementation, a method of manufacturing a duct includes applying insulation to an exterior surface of a rigid air-permeable tube of composite material to form a layer of insulation on the exterior surface of the rigid air-permeable tube. The method further includes applying non-rigid insulation to an exterior surface of the layer of insulation to form a non-rigid insulation layer in contact with the layer of insulation, the non-rigid insulation layer forming an air-impermeable duct wall.

In another particular implementation, a method of manufacturing a duct includes inserting insulation into a rigid tube of composite material to form a layer of insulation within the rigid tube. The layer of insulation is in contact with an inner surface of the rigid tube. The method further includes inserting a biasing member into the rigid tube of composite material to secure the layer of insulation within the rigid tube.

In yet another particular implementation, a duct includes a foam-filled honeycomb core structure having a tubular shape. The duct further includes an air-impermeable duct wall coupled to an exterior surface of the foam-filled honeycomb core structure.

In yet another particular implementation, a method of manufacturing a duct includes generating a honeycomb core structure having a tubular shape. The honeycomb core structure includes a plurality of hexagonal shaped cavities. The method also includes filling the plurality of hexagonal shaped cavities of the honeycomb core structure with foam to generate a foam-filled honeycomb core structure. The method further includes coupling an air-impermeable duct wall to an exterior surface of the foam-filled honeycomb core structure.

In a particular implementation, a method of installing a duct on a vehicle includes installing the duct in an environmental control system of the vehicle where the duct includes a foam-filled honeycomb core structure having a tubular shape and an air-impermeable duct wall coupled to an exterior surface of the foam-filled honeycomb core structure.

By using one of the ducts described herein, an environmental control system can more efficiently meet acoustic design requirements, achieve better thermal performance, achieve a lower weight and volume configuration, and reduce costs.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram that illustrates examples of ducts;

FIG. **2** is a block diagram of an aircraft that includes an example of an environmental control system including one of the ducts of FIG. **1**;

FIG. **3** is a diagram that illustrates a perspective view of an example of the environmental control system of FIG. **2**;

FIG. **4**A is a diagram that illustrates a cross-section view of an example of one of the ducts of FIG. **1**;

FIG. **4**B is a diagram that illustrates a cross-section view of an example of another of the ducts of FIG. **1**;

FIG. **5**A is a diagram that illustrates a side view of an example of the duct of FIG. **4**A;

FIG. **5**B is a diagram that illustrates a cross-section view of the duct of FIG. **5**A;

FIG. **6** is a diagram that illustrates a cross-section view of another example the duct of FIG. **4**A;

FIG. **7** is a diagram that illustrates a cross-section view of another example of the duct of FIG. **4**A;

FIG. **8**A is a diagram that illustrates a cross-section view of an example of the duct of FIG. **4**B including a sleeve;

FIG. **8**B is a diagram that illustrates a cross-section view of an example of the duct of FIG. **4**B including an internal coupler;

FIG. **9** is a diagram that illustrates a cross-section view of a particular example of the duct of FIG. **4**B;

FIG. **10** is a diagram that illustrates a detailed cross-section view of a duct including an example of an internal coupler;

FIG. **11**A is a diagram that illustrates a cross-section view of an example of a duct including a foam-filled honeycomb core structure;

FIG. **11**B is a diagram that illustrates the foam-filled honeycomb core structure including a plurality of cavities of the duct of FIG. **11**A;

FIG. **11**C is a diagram that illustrates the foam-filled honeycomb core structure including foam of the duct of FIG. **11**A;

FIG. **11**D is a diagram that illustrates the foam-filled honeycomb core structure and an air-impermeable duct wall of the duct of FIG. **11**A;

FIG. **12**A is a diagram that illustrates a cross-section view of an example of the duct of FIG. **11**A including an interior layer;

FIG. **12**B is a diagram that illustrates a particular example of the duct of FIG. **12**A;

FIG. **12**C is a diagram that illustrates another example of the duct of FIG. **12**A;

FIG. **12**D is a diagram that illustrates another example of the duct of FIG. **12**A;

FIG. **13** is a diagram that illustrates an example of perforations of a rigid tube of a duct;

FIG. **14** is a flow chart of an example of a method of manufacturing a duct;

FIG. **15** is a flow chart of another example of a method of manufacturing a duct;

FIG. **16** is a flow chart of another example of a method of manufacturing a duct;

FIG. **17** is a flow chart of an example of a method of duct manufacturing and service;

FIG. **18** is a block diagram that illustrates an example of a vehicle including a duct; and

FIG. **19** is a diagram that illustrates a top view of an example of an aircraft including the environmental control system of FIG. **2**.

DETAILED DESCRIPTION

The disclosed embodiments provide ducts that absorb sound for use in environmental control systems. Methods of manufacturing the ducts are also disclosed. A duct according to particular aspects discloses herein can function as a noise attenuating muffler and can reduce the use of dedicated noise attenuating mufflers in an environmental control system. For example, conventional ducts and noise attenuating mufflers may be replaced with the disclosed ducts.

In a first implementation, a first duct (e.g., a first type of duct) includes a rigid air-permeable tube of composite material forming an interior surface or wall of the first duct. The first duct also includes a layer of insulation (e.g., foam or felt) and a non-rigid outer liner. The non-rigid outer liner seals the ducts to form an air-impermeable duct wall and provides an outer layer or second layer of thermal and sound insulation. As compared to conventional ducts which include a rigid outer wall (or a rigid outer wall wrapped in non-rigid thermal insulation), the first duct includes a non-rigid outer liner that seals the duct and provides thermal insulation (and some sound absorption). As compared to conventional ducts, the first duct is lighter and less expensive to produce.

In a second implementation, a second duct (e.g., a second type of duct) includes a rigid tube of composite material and an insulation layer disposed within the rigid tube. The second duct further includes a biasing member (e.g., a spring) disposed within the rigid tube which secures the insulation layer against an interior surface of the rigid tube. Similar to the first duct, the second duct has one rigid component, i.e., the outer layer or tube. Conventional ducts often have two or more rigid components. Accordingly, as compared to conventional ducts, the second duct is lighter and less expensive to produce.

In a third implementation, a third duct (e.g., a third type of duct) includes a foam-filled honeycomb core structure having a tubular shape and an air-impermeable duct wall coupled to an exterior surface of the foam-filled honeycomb core structure. The foam-filled honeycomb core structure includes a plurality cavities filled with foam. The air-impermeable duct wall (e.g., thermoplastic film or rigid composite tube) is coupled to the foam-filled honeycomb core structure to seal the third duct. In some implementations, the third duct further includes an interior layer. For example, the third duct further includes a rigid air-permeable tube of composite material or a layer of foam as the interior layer. As compared to conventional ducts, the third duct is stronger and lighter because its "insulation layer," the foam-filled honeycomb core structure, provides structural support and stability. The foam-filled honeycomb core structure enables the air-impermeable duct wall to be a non-rigid outer liner (e.g., thermoplastic film) or a relatively thin layer of composite material (as compared to conventional ducts where the outer layer provides structural stability). For example, the composite material may be only one or two plies thick.

A technical effect of embodiments described herein enable an environmental control system to be lighter, smaller, or less expensive than other ducts not having at least some of these features. Accordingly, vehicles that include such environmental control system can be lighter, smaller, and less expensive.

FIG. **1** illustrates a block diagram **100** of examples of ducts **102**. The ducts **102** may be include in an environmental control system, such as an environmental control system **202** of FIG. **2**. The ducts **102** may be included in a vehicle, such as the aircraft **200** of FIG. **2**.

The duct **102**A includes a rigid air-permeable tube of composite material **112** (also referred to herein as a rigid air-permeable tube **112**), a layer of insulation **114**, and a non-rigid insulation layer **116**. The rigid air-permeable tube of composite material **112** includes or corresponds to tube of composite material formed from "open" weave composite material or a rigid perforated tube **136**. Open weave composite materials include composite material having an arrangement or pattern of fibers that is open loop. Examples of open loop arrangements include a leno weave arrangement (a.k.a., a gauze weave or cross weave arrangement). The leno weave arrangement is a type of plain weave in which adjacent "warp" fibers are twisted around consecutive "weft" fibers to form a spiral pair, effectively 'locking' each weft in place. An open weave composite material tube **132** includes (e.g., is formed from) a few plies of open weave composite material such that when the open weave composite material is cured the open weave composite material tube **132** contains openings in which air can pass through (i.e., is air-permeable). The air permeability of the open weave composite material tube **132** enables the duct **102**A to absorb sound like a noise attenuating muffler.

The rigid perforated tube **136** includes a plurality of perforations (e.g., perforations **1312** of FIG. **13**) such that air can pass through the perforations and the rigid perforated tube **136**. In some implementations, the rigid perforated tube **136** includes or corresponds to a tube of composite material formed from "closed" weave composite materials.

The layer of insulation **114** is coupled to an exterior surface of the rigid air-permeable tube **112** and comprises a middle layer of the duct **102**A. The layer of insulation **114** is configured to provide thermal insulation and/or sound absorption. The layer of insulation **114** includes a layer of foam or felt. As illustrative, non-limiting examples, the layer of insulation **114** includes open cell foam **152** or aramid felt **154**.

In some implementations, the open cell foam **152** has a spiral wrapped configuration. To illustrate, the open cell foam **152** is in strips or triangles and is wrapped around the exterior of the rigid air-permeable tube of composite material **112**. As an illustrative, non-limiting example, the open cell foam **152** includes or corresponds to melamine foam. The aramid felt **154** includes aramid fibers, such as meta-aramid fibers, para-aramid fibers, or a combination thereof, which are matted, condensed, and/or pressed together. As an illustrative, non-limiting examples, the aramid felt **154** may include or correspond to a meta-aramid felt (e.g., a Nomex felt material—Nomex is a registered trademark of DuPont) or a para-aramid felt.

The non-rigid insulation layer **116** is in contact with the layer of insulation **114**, and the non-rigid insulation layer **116** forms an air-impermeable duct wall. The non-rigid insulation layer **116** is configured to provide thermal insulation and to seal the duct **102**A. In some implementations, the non-rigid insulation layer **116** absorbs sound. The non-rigid insulation layer **116** includes or corresponds to a layer of thermoplastic film **162** or a layer of high mass fabric **164** that acts as an outer liner of the duct **102**A. The layer of thermoplastic film **162** may include a polyetherketoneketone (PEKK) film, a polyether ether ketone (PEEK) film, a Poly Vinyl Fluoride (PVF), a non-flammable material pressure-sensitive tape, or a combination thereof (e.g., a first layer of PEKK film and a second layer of PEEK film). In some implementations, the layer of thermoplastic film **162** includes one to two plies or layers of thermoplastic material. The high mass fabric **162** as used herein includes materials made of natural or synthetic fibers that produce a fabric having an areal density (a.k.a., basis weight) greater than about 15 ounces per square yard. Such an areal density provides sound blocking (e.g., reducing or preventing break-out noise through a cross section of the duct), thermal insulation, and can act as an air-impermeable liner.

The duct **102**B includes a biasing member **122**, an insulation layer **124**, and a rigid tube of composite material **126**. The rigid tube of composite material **126** is configured to support the duct **102**B. The rigid tube of composite material **126** may include or correspond an arrangement of composite material that is non-permeable and forms an air-impermeable exterior duct wall.

The biasing member **122** is disposed within the rigid tube of composite material **126** and is configured to restrain the insulation layer **124** within the rigid tube of composite material **126**. For example, the biasing member **122** exerts a force (e.g., a radially outward force) that secures and restrains the insulation layer **124** against an interior surface of the rigid tube of composite material **126**. In some implementations, the biasing member **122** includes or corresponds to a spring, such as the spring **822** of FIG. **8**A and FIG. **8**B. As an illustrative, non-limiting example, the biasing member **122** is a helical compression spring.

The insulation layer **124** is configured to absorb sound and provide thermal insulation. The insulation layer **124** includes the open cell foam **152**, the aramid felt **154**, the high mass fabric **164**, or a combination thereof. As an illustrative, non-limiting example the insulation layer **124** includes a layer of Nomex felt.

The duct **102**C includes a foam-filled honeycomb core structure **144** and an air-impermeable duct wall **146**. The foam-filled honeycomb core structure **144** has a tubular shape. To illustrate, the foam-filled honeycomb core structure **144** defines an inlet and an outlet opposing the inlet. The foam-filled honeycomb core structure **144** has an interior surface and an exterior surface that opposes the interior surface. The foam-filled honeycomb core structure **144** includes a core structure **172** that defines a plurality of cavities **174**, as depicted in FIGS. **11**B-**11**D. The foam-filled honeycomb core structure **144** includes foam **176** within the plurality of cavities **174**. The foam **176** may include or correspond to the open cell foam **152**, a closed cell foam **134**, or a combination thereof.

The air-impermeable duct wall **146** is coupled to an exterior surface of the foam-filled honeycomb core structure **144**. The air-impermeable duct wall **146** is configured to seal the duct **102**C. The air-impermeable duct wall **146** may be flexible or rigid. For example, the air-impermeable duct wall **146** may include or corresponds to a layer of the thermoplastic film **162**, a layer of the high mass fabric **164**, or a rigid tube **166**. The rigid tube **166** can be made from composite materials, plastic, metal, of a combination there.

In some implementations, the duct **102**C further includes an interior layer coupled to an interior surface of the foam-filled honeycomb core structure **144**. For example, the duct **102**C further includes the open weave composite material tube **132**, a layer of closed cell foam **134**, or the rigid perforated tube **136** coupled to the interior surface of the foam-filled honeycomb core structure **144**.

In some implementations, the ducts **102**A-**102**C include adhesive material, such as the adhesive material **522** of FIG. **5**A, to couple a first duct to a second duct or another component via coupler, such as a sleeve **512** of FIG. **5**A or FIG. **5**B or an internal coupler **812** of FIG. **8**B, as further described herein. Additionally or alternatively, the duct **102**A includes adhesive tape, such as adhesive tape **622** of FIG. **6**, coupled to the layer of insulation **114**, to the non-rigid insulation layer **116**, or to both. In addition, the duct **102**B may include adhesive tape, such as the adhesive tape **622** of FIG. **6**, coupled to the insulation layer **124**. The ducts **102**A-**102**C may be manufactured by exemplary methods of manufacturing described with reference to FIGS. **14**-**16**.

In operation, the ducts **102**A-**102**C are configured to transport treated air, provide thermal insulation, provide sound absorption, provide sound blocking, and provide structural integrity for positive and negative pressure applications. Operation of the ducts **102**A-**102**C are described further with reference to FIG. **3**.

FIG. **2** is a block diagram of an aircraft **200** that includes an example of an environmental control system (ECS) **202** which includes one of the ducts **102**A-**102**C of FIG. **1**. In other implementations, the ECS **202** is included on other vehicles, such as a rocket, a helicopter, a car, a bus, a train, a ship, a submarine, etc.

As illustrated in FIG. **2**, the ECS **202** includes a duct system **212**, an air conditioning unit **214**, an intake port **222**, and an exhaust port **224**. The duct system **212** is configured to provide treated fluid (e.g., treated air **352** of FIG. **3**) to passengers of the aircraft **200**. The duct system **212** includes or more ducts. As illustrated in FIG. **2**, the duct system **212** includes first zone ducts **232**, riser ducts **234**, second zone ducts **236**, and outlet ports **238**.

One or more of the first zone ducts **232**, the riser ducts **234**, and the second zone ducts **236** may include the ducts **102**A-**102**C of FIG. **1**. As illustrated in the implementation of FIG. **2**, the first zone ducts **232** include at least one of the ducts **102**A-**102**C of FIG. **1**. The first zone ducts **232**, the riser ducts **234**, and the second zone ducts **236** are configured to transport fluid through the duct system **212**.

The outlet ports **238** are configured to provide the fluid to the passengers. For example, the outlet ports **238** include or correspond to cabin or passenger vents. The outlet ports **238** may be controllable (e.g., opened or closed) by the passengers. The outlet ports **238** may be coupled to the first zone ducts **232**, the riser ducts **234**, the second zone ducts **236**, or a combination thereof.

The air conditioning unit **214** is in fluid communication with the duct system **212** and is configured to condition or treat fluid (e.g., air) within the ECS **202**. The intake port **222** is in fluid communication with the duct system **212** and is configured to intake or receive fluid (e.g., air) into the ECS **202**. For example, the intake port **222** may intake fluid from within the aircraft **200** (e.g., a pressurized compartment and/or cabin of the aircraft **200**) or from outside the aircraft **200** (e.g., ambient or unpressurized air).

The exhaust port **224** is in fluid communication with the duct system **212** and is configured to exhaust or expend fluid (e.g., air). For example, the exhaust port **224** may exhaust fluid outside of the aircraft **200** or out of the ECS **202** (e.g., exhaust to fluid to a filter or another system of the aircraft **200**). Although the ECS **202** of FIG. **2** includes the air conditioning unit **214**, in other implementations the ECS **202** may include other components (e.g., a heater, electrical equipment, an exhaust system, a fan, orifices, etc., or a combination thereof) in addition to or in the alternative of the air conditioning unit **214**. Operation of the ECS **202** of FIG. **2** is described with reference to FIG. **3**.

FIG. **3** is a diagram **300** that illustrates a particular example of the environmental control system (ECS) **202** of FIG. **2**. In FIG. **3**, the first zone ducts **232** are located below a cabin **312** (e.g., in an area **314** below a floor **322** of the cabin **312**) of the aircraft **200**, the riser ducts **234** are located between the cabin **312** and an exterior (e.g., skin) of the aircraft **200**, the second zone ducts **236** are located above a ceiling **324** of the cabin **312** (e.g., in a crown **316** of the aircraft **200**).

During operation, treated air **352** from the air conditioning unit **214** (and/or the intake port **222**) is received by the first zone ducts **232**. The first zone ducts **232** transport the treated air **352** through the first zone ducts **232** and to the riser ducts **234**. As the treated air **352** moves through the first zone ducts **232**, the treated air **352** generates noise. Additionally or alternatively, noise is generated by fans, duct geometry, flow control devices, object in a flow path of the treated air **352**, or a combination thereof. The first zone ducts **232** attenuate the noise and provide thermal insulation such that heat of ambient air (e.g., air external to the ECS **202**) is not transferred to the treated air **352** and that heat of the treated air **352** is not transferred to the ambient air.

The riser ducts **234** transport the treated air **352** through the riser ducts **234** and to the second zone ducts **236**. In some implementations, the riser ducts **234** also transport the treated air **352** to the outlet ports **238**, where the treated air **352** can be controlled by passengers. As the treated air **352** moves through the riser ducts **234**, the treated air **352** generates noise. The riser ducts **234** attenuate the noise and provide thermal insulation.

The second zone ducts **236** transport the treated air **352** through the second zone ducts **236** and to air conditioning unit **214** (and/or exhaust port **224**). In other implementations, the second zone ducts **236** transport the treated air **352** to the outlet ports **238**, where the treated air **352** can be controlled by passengers. As the treated air **352** moves through the second zone ducts **236**, the treated air **352** generates noise. The second zone ducts **236** attenuate the noise and provide thermal insulation.

As illustrated in FIG. **3**, the exemplary ECS **202** is free of distinct noise attenuating mufflers (e.g., zone mufflers). For example, the ECS **202** does not include duct sections that have external noise attenuating mufflers encasing the duct sections and/or duct and dedicated noise attenuating muffler combination sections configured to absorb sound above or below the cabin **312**, as in a conventional ECS.

FIGS. **4**A and **4**B illustrate a cross-section view of an example of the duct **102**A and an example of the duct **102**B. In FIGS. **4**A and **4**B, the examples of the ducts **102**A and **102**B are curved. In other examples, such as in FIGS. **5** and **8**, the ducts **102**A-**102**C are straight. In FIG. **4**A, the duct **102**A includes the rigid air-permeable tube **112**, the layer of insulation **114**, the non-rigid insulation layer **116**. In FIG. **4**B, the duct **102**B includes the biasing member **122**, the insulation layer **124**, and the rigid tube of composite material **126**. Additional examples of the ducts **102**A and **102**B are illustrated in FIGS. **5**A, **5**B, **6**, **7**, **8**A, **8**B, **9**, and **10**.

FIGS. **5**A and **5**B illustrate a side view and a cross-section view (e.g., a longitudinal cross-section) of a particular example of the duct **102**A. In FIGS. **5**A and **5**B, the duct **102**A includes the rigid air-permeable tube **112**, the layer of insulation **114**, the non-rigid insulation layer **116**, and a sleeve **512**. The sleeve **512** is coupled to an exterior surface of the rigid air-permeable tube **112** via adhesive material **522**. The sleeve **512** is configured to overlap a portion of an end of the rigid air-permeable tube **112** of the duct **102**A and to overlap a portion of an end of a second duct **102**A to couple the duct **102**A and the second duct **102**A in fluid communication.

The adhesive material **522** includes a material configured to bond the sleeve **512** to the rigid air-permeable tube **112**. For example, the adhesive material **522** includes silicone or a pressure sensitive adhesive. As an illustrative, non-limiting example, the adhesive material **522** includes Room-Temperature-Vulcanizing (RTV) silicone. As illustrated in FIG. **5**A, the adhesive material **522** is in contact with the rigid air-permeable tube **112**, which extends past the layer of insulation **114** and the non-rigid insulation layer **116**.

As illustrated in FIG. **5**A, the sleeve **512** is smaller (e.g., has a smaller diameter) than the duct **102**A (e.g., a diameter of the non-rigid insulation layer **116** thereof). In other implementations, the sleeve **512** is the same size as or is larger than the duct **102**A (e.g., the diameter of the non-rigid insulation layer **116** thereof).

FIG. **5**B depicts the cross-section view (e.g., a longitudinal cross-section) of the duct **102**A of FIG. **5**A. In FIG. **5**B, an area **532** represents a portion of the duct **102**A where adhesive tape, such as the adhesive tape **622** of FIG. **6**, can be used to seal the joints or couplings between ducts **102**A. For example, the adhesive tape (not shown) can be used to seal the edges between the ducts **102**A and the sleeve **512**, as further described with reference to FIG. **6**. In other implementations, the duct **102**A includes an internal coupler, such as internal coupler **812** of FIG. **8**B, to couple to a second duct **102**A, as described with reference to FIGS. **8**B and **10**.

FIG. **6** is a diagram **600** that illustrates a cross-section view (e.g., a transverse or circumferential cross-section) of another example of the duct **102**A. In FIG. **6**, the duct **102**A includes the open weave composite material tube **132** for the rigid air-permeable tube **112**, a layer of the aramid felt **154** for the layer of insulation **114**, and a layer of the thermoplastic film **162** for the non-rigid insulation layer **116**. In the example illustrated in FIG. **6**, the layer of aramid felt **154** includes one ply of the Nomex felt and the layer of the thermoplastic film **162** includes one or two layers (e.g., plies) of a PEEK film.

The layer of the aramid felt **154** and the layer of the thermoplastic film **162** each form a seam **612**. For example, the aramid felt **154** is wrapped around the open weave composite material tube **132** and creates the seam **612**, and the thermoplastic film **162** is wrapped around the layer of aramid felt **154** and creates a seam **612**.

In FIG. **6**, the duct **102**A further includes the adhesive tape **622** positioned proximate to (e.g., over) the seams **612**. The adhesive tape **622** is configured to restrain the layer of insulation **114** (i.e., the layer of aramid felt **154**), the non-rigid insulation layer **116** (i.e., the layer of thermoplastic film **162**), or both. In some implementations, the adhesive tape **622** includes or corresponds to pressure sensitive tape. As an illustrative, non-limiting example, the adhesive tape **622** includes a metalized polyether ether ketone (MPEEK) material. In other implementations, the non-rigid insulation layer **116** includes a layer of the high mass fabric **164**. For example, the non-rigid insulation layer **116** includes one to two layers (e.g., plies) of the high mass fabric **164** wrapped around the layer of the aramid felt **154**.

FIG. **7** is a diagram **700** that illustrates a cross-section view (e.g., a transverse or circumferential cross-section) of another example of the duct **102**A. In FIG. **7**, the duct **102**A includes the open weave composite material tube **132** for the rigid air-permeable tube **112**, a layer of the open cell foam **152** for the layer of insulation **114**, and a layer of the thermoplastic film **162** for the non-rigid insulation layer **116**. In the example illustrated in FIG. **6**, the layer of the open cell foam **152** includes a layer of spiral wrapped melamine foam and the layer of the thermoplastic film **162** includes one or two layers (e.g., plies) of a PEEK film. In some implementations, the layer of spiral wrapped melamine foam includes multiple plies (e.g., three to four plies) of compressed melamine foam that is wrapped around the open weave composite material tube **132** in a spiral.

As compared to the duct **102**A of FIG. **6** that includes the layer of the aramid felt **154**, the duct **102**A of FIG. **7** includes the layer of open cell foam **152**. The layer of open cell foam **152** provides higher thermal resistance as compared to the aramid felt **154** or Nomex foam. Open cell foam **152** provides similar sound absorption to the aramid felt **154** at less cost and weight. The aramid felt **154** provides higher sound absorption (e.g., absorption and reduction of breakout noise) and transmission loss (e.g., noise reduction from an inlet of the duct **102**A to an outlet of the duct **102**A), as compared to a similar mass of the open cell foam **152**.

FIGS. **8**A and **8**B each illustrate a cross-section view (e.g., a longitudinal cross-section) of an example of the duct **102**B including a coupler. In FIGS. **8**A and **8**B the duct **102**B includes a spring **822** for the biasing member **122**, a layer of the aramid felt **154** for the insulation layer **124**, and the rigid tube of composite material **126**. In the example illustrated in FIGS. **8**A and **8**B, the spring **822** includes a helical compression spring and the layer of aramid felt **154** includes one ply of the Nomex felt.

Referring to FIG. **8**A, a first example of the duct **102**B including the sleeve **512** is illustrated. In FIG. **8**A, the sleeve **512** (e.g., an external coupler) is in contact with an exterior of the duct **102**B, that is an exterior surface of the rigid tube of composite material **126**, as opposed to the sleeve **512** of FIG. **5**A that is in contact with the exterior surface of the rigid air-permeable tube of composite material **112** of the duct **102**A.

In FIG. **8**B, a second example of the duct **102**B includes an internal coupler **812**. In some implementations, the internal coupler **812** includes threads (not shown), a bead **814**, or a combination thereof, to couple and secure sections of ducts **102**B together. As illustrated in FIG. **8**B, the internal coupler **812** includes the bead **814** (e.g., a protrusion) which engages with a surface (internal surface) of a second duct **102**B or a sleeve **512**. The bead **814** exerts force to keep the ducts **102**B together and generates friction which oppose the ducts **102**B from decoupling. For example, the bead **814** exerts a force on the sleeve **512** that is coupled to the ducts **102**B by a hose clamp or a plastic zip tie. The internal coupler **812** is described further with reference to FIG. **10**.

Although, the ducts **102**B are shown with two sleeves **512** or two internal couplers **812** in FIGS. **8**A and **8**B, in other implementations, a particular duct (e.g., one of the ducts **102**A-**102**C) can include one sleeve **512** and one internal coupler **812**.

FIG. **9** is a diagram **900** that illustrates a cross-section view (e.g., a transverse or circumferential cross-section) of a particular example of the duct **102**B. In FIG. **9**, the duct **102**B includes the spring **822** for the biasing member **122**, a layer of the aramid felt **154** for the insulation layer **124**, and the rigid tube of composite material **126**. In the example illustrated in FIG. **9**, the layer of aramid felt **154** includes one ply of the Nomex felt.

FIG. **10** is a diagram **1000** that illustrates a detailed cross-section view (longitudinal cross-section) of the internal coupler **812** of FIG. **8**B. In FIG. **10**, the internal coupler **812** is a "reducer," i.e., the internal coupler **812** reduces an outside diameter **1012**, **1014** of the ducts **102**B. To illustrate, a first outside diameter **1012** of the first duct **102**B is larger than a second outside diameter **1014** of an interior portion of the internal coupler **812** (and of a second duct **102**B which is coupled to the ducts **102**B via the internal coupler **812**. An exterior portion (e.g., a portion near the bead **814**) of the internal coupler **812** has an outside diameter, a third outside diameter **1016**, that is less than the first outside diameter **1012** of the first duct **102**B and the second outside diameter **1014** of the interior portion of the internal coupler **812**. In some implementations, the second duct **102**B and/or a sleeve (e.g., the sleeve **512**) is coupled to internal coupler **812** and contacts the bead **814**. The second duct **102**B and/or the sleeve **512** may be secured to the first duct **102**B by a hose clamp or a plastic zip tie.

In FIG. **10**, an inside diameter **1018** of the duct **102**B and the second duct **102**B remains the same. In other implementations, the internal coupler **812** has an inside diameter **1018** that is smaller than the inside diameter **1018** of the duct **102**B and the internal coupler **812** reduces the inside diameter **1018** of the second duct **102**B in addition or in the alternative to reducing the first outside diameter **1012** of the ducts **102**B. The internal coupler **812** includes a polymer, a composite material, a metal, or a combination thereof.

FIGS. **11**A-**11**D illustrate a particular example of the duct **102**C and the foam-filled honeycomb core structure **144** thereof. FIG. **11**A is a diagram that illustrates a cross-section view of the duct **102**C. In FIG. **11**A, the duct **102**C has the foam-filled honeycomb core structure **144** and the air-impermeable duct wall **146**. The foam-filled honeycomb core structure **144** includes the plurality of cavities **174**, as illustrated in FIG. **11**B.

FIG. **11**B depicts surfaces of the foam-filled honeycomb core structure **144** defining the plurality of cavities **174**. The plurality of cavities **174** have a hexagonal shape (e.g., a honeycomb shape). In other implementations, one or more of the plurality of cavities **174** have other shapes, such as a circular shape, a rectangular shape, a square shape, a pentagonal shape, an octagonal shape, another shape that may be tessellated, or a combination thereof. The plurality of cavities **174** are illustrated in FIG. **11**B as extending through the foam-filled honeycomb core structure **144**, i.e., the plurality of cavities **174** correspond to through holes and are defined by both surfaces of the foam-filled honeycomb core structure **144**. In other implementations, the plurality of cavities **174** do not extend through the foam-filled honeycomb core structure **144**. In a particular implementation, each of the surfaces of the foam-filled honeycomb core structure **144** defines a corresponding plurality of cavities **174**.

FIG. **11**C depicts the foam **176** in the plurality of cavities **174** of the foam-filled honeycomb core structure **144**. As illustrated in FIG. **11**C, the foam **176** (e.g., the closed cell foam **134** or the open cell foam **152** extends to the surfaces of the foam-filled honeycomb core structure **144**. In other implementations, the foam **176** terminates before or extends past the surfaces of the foam-filled honeycomb core structure **144**. The foam **176** may be grown in-situ (i.e., within the plurality of cavities **174**) or may be inserted into the plurality of cavities **174**.

The foam-filled honeycomb core structure **144** (e.g., portions thereof) includes one or more layers (e.g., the air-impermeable duct wall **146**) coupled to the surfaces of the foam-filled honeycomb core structure **144** that define the plurality of cavities **174**, as illustrated in FIG. **11**D. In a particular implementation, the air-impermeable duct wall **146** includes composite material.

FIG. **12**A illustrates a cross-section view of an example of the duct **102**C including an interior layer. In FIG. **12**A, the duct **102**C includes the foam-filled honeycomb core structure **144**, the air-impermeable duct wall **146**, and one of the interior layers described with reference to FIG. **1**. For example, the duct **102**C includes one of the open weave composite material tube **132**, the layer of closed cell foam **134**, or the rigid perforated tube **136**.

FIG. **12**B depicts an example of the duct **102**C of FIG. **12**A the foam-filled honeycomb core structure **144** positioned (e.g., sandwiched) between two layers. In FIG. **12**B, the foam-filled honeycomb core structure **144** is positioned between the open weave composite material tube **132** and a layer of the thermoplastic film **162**.

FIG. **12**C depicts another example of the duct **102**C of FIG. **12**A where the foam-filled honeycomb core structure **144** is positioned between the layer of closed cell foam **134** and a layer of the thermoplastic film **162**.

FIG. **12**D depicts another example of the duct **102**C of FIG. **12**A where the foam-filled honeycomb core structure **144** is positioned between the rigid perforated tube **136** and a layer of the thermoplastic film **162**.

FIG. **13** is a diagram **1300** that illustrates an example of the perforations **1312** of the rigid tube **166** of the duct **102**C. As illustrated in FIG. **13**, the duct **102**C is curved and the perforations **1312** have a circular cross-section. In other implementations, the duct **102**C is straight and/or the perforations **1312** have a cross-section that is non-circular, such as an elliptical cross-section, a rectangular cross-section, a square cross-section, a triangular cross-section, or a hexagonal cross-section. In some implementations, the perforations **1312** are arranged in a pattern. For example, the perforations **1312** can be arranged in an asymmetrical pattern or a symmetrical pattern. To illustrate, when the perforations **1312** are symmetrical, the perforations **1312** may be symmetrical with respect to an axis or curvature of the duct **102**C.

The perforations **1312** are configured to allow air and/or sound waves to pass from an interior of the rigid tube **166** to another layer of the duct **102**C. The perforations **1312** of the rigid tube **166** enable the duct **102**C to function similar to a muffler, i.e., to reduce sound generated by air moving through the duct **102**C and an ECS. To illustrate, as a sound wave propagates to the perforations **1312**, a portion of the sound wave passes through the perforations **1312** to an insulation layer or material of the duct **102**C where it is absorbed.

In some implementations, the perforations **1312** are sized to cause destructive interference (i.e., reduce noise by canceling out sound waves generated by the air moving through duct **102**C). To illustrate, when the sound wave propagates to the perforations **1312**, another portion of the sound wave is reflected back into the interior of the rigid tube **166**. The other portion of the sound wave may cause destructive interference with another sound wave and may cancel out at least a portion of the other sound wave. A size of the perforations **1312** is based on a size (e.g., length and/or diameter) of the rigid tube **166**, a speed of the air, a pressure of the air, or a combination thereof.

FIG. **14** illustrates a particular example of a method **1400** of manufacturing a duct, such as the ducts **102**A of FIG. **1**. The method **1400** includes, at **1402**, applying insulation to an exterior surface of a rigid air-permeable tube of composite material to form a layer of insulation on the exterior surface of the rigid air-permeable tube. For example, the layer of insulation may include or correspond to the layer of insulation **114**, the open cell foam **152**, or the aramid felt **154** of FIG. **1**. The rigid air-permeable tube of composite material may include or correspond to the rigid air-permeable tube of composite material **112** of FIG. **1**. To illustrate, the layer of insulation **114** is formed by wrapping insulation (e.g., the open cell foam **152**, the aramid felt **154**, or both) around the outside or exterior of the rigid air-permeable tube of composite material **112**. In a particular implementation, the composite material of the rigid air-permeable tube **112** includes a fabric material having a leno weave arrangement. In a particular implementation, after the insulation is applied, a leak check or test is performed on the combined rigid air-permeable tube and layer of insulation.

The method **1400** further includes, at **1404**, applying non-rigid insulation to an exterior surface of the layer of insulation to form a non-rigid insulation layer in contact with the layer of insulation, the non-rigid insulation layer forming an air-impermeable duct wall. For example, the non-rigid insulation layer may include or correspond to the non-rigid insulation layer **116**, the thermoplastic film **162**, or the high mass fabric **164** of FIG. **1**. To illustrate, the non-rigid insulation layer is formed by is wrapping the non-rigid insulation (e.g., the thermoplastic film **162** or the high mass fabric **164**) around the outside or exterior of the layer of insulation **114**.

In some implementations, the rigid air-permeable tube comprises a rigid, perforated tube of composite material. In such implementations, the method **1400** includes, prior to applying **1402** the insulation to the exterior surface of a rigid air-permeable tube, generating **1412** the rigid, perforated tube. In some such implementations, generating **1412** includes curing **1422** the composite material into a rigid tube and generating **1424** perforations in the rigid tube to form the rigid, perforated tube. To illustrate, composite material is applied to an exterior surface of a tubular tool or mandrel and the composite material is cured to form the rigid tube by applying heat, light, pressure (plenum pressure or vacuum pressure), or a combination thereof to the composite material. Perforations are generated in the rigid tube by machining the rigid tube to form the rigid, perforated tube of composite material.

In other implementations, generating **1412** includes applying the composite materials onto a tool to form the rigid, perforated tube such that the perforations are formed during curing of the composite materials. For example, a tool used as the layup surface for the composite materials includes protrusions such that the when the composite material is cured, the protrusions case perforations in the rigid, perforated tube.

In some implementations, the method **1400** further includes, at **1414**, applying adhesive tape to the layer of insulation, the non-rigid insulation layer, or both, to secure the layer of insulation to the rigid air-permeable tube, to secure the non-rigid insulation layer to the layer of insulation, or both. For example, the adhesive tape includes or corresponds to the adhesive tape **622** of FIG. **6**. To illustrate, 1 ply of MPEEK adhesive tape is placed along the seams **612** of the layer of insulation **114** and of the non-rigid insulation layer **116** to secure the layers and to seal the duct **102**A.

FIG. **15** illustrates another example of a method **1500** of manufacturing a duct, such as the ducts **102**B of FIG. **1**. The method **1500** includes, at **1502**, inserting insulation into a rigid tube of composite material to form a layer of insulation within the rigid tube, the layer of insulation in contact with an inner surface of the rigid tube. For example, the layer of insulation may include or correspond to the insulation layer **124**, the open cell foam **152**, the aramid felt **154**, or the high mass fabric **164** of FIG. **1**. The rigid tube of composite material may include or correspond to the rigid tube of composite material **126** of FIG. **1**. To illustrate, the insulation layer **124** is formed by wrapping insulation (e.g., the open cell foam **152**, the aramid felt **154**, the high mass fabric **164**, or a combination thereof) around the inside or interior of the rigid tube of composite material **126**.

The method **1500** further includes, at **1504**, inserting a biasing member into the rigid tube of composite material to secure the layer of insulation within the rigid tube. For example, the biasing member may include or correspond to the biasing member **122** or the spring **822** of FIG. **8**A and FIG. **8**B. To illustrate, the biasing member **122** is inserted into the inside or interior of the rigid tube of composite material **126** via and inlet or outlet of the rigid tube of composite material **126**. In some such implementations, the insulation may be coupled or secured to the rigid tube of composite material **126** by the adhesive tape **622** or the insulation may couple to itself by the adhesive tape **622** to form a tubular shape and the insulation layer **124**.

In some implementations, the method **1500** includes, prior to inserting the insulation, coupling **1512** the insulation to the biasing member. To illustrate, the insulation (e.g., the open cell foam **152**, the aramid felt **154**, the high mass fabric **164**, or a combination thereof) is wrapped around or applied to the exterior or outside of the biasing member **122** to form the insulation layer **124**, and then, the combined insulation layer **124** and the biasing member **122** is inserted into the rigid tube of composite material **126** to form the duct **102**B. For example, the insulation layer **124** and the biasing member **122** are inserted into the rigid tube of composite material **126** as a unitary piece. In some such implementations, the insulation may be coupled or secured to the biasing member **122** by the adhesive tape **622**. Alternatively, adhesive material **522** couples or secures the insulation to the biasing member **122** or the biasing member **122** (e.g., the spring **822**) is threaded through the insulation to couple or secure the insulation to the biasing member **122**.

FIG. **16** illustrates a particular example of a method **1600** of manufacturing a duct, such as the ducts **102**B of FIG. **1**. The method **1600** includes, at **1602**, generating a honeycomb core structure having a tubular shape, the honeycomb core structure including a plurality of hexagonal shaped cavities. For example, the honeycomb core structure may include or correspond to the core structure **172** of FIG. **1** and the plurality of hexagonal shaped cavities may include or correspond to the plurality of cavities **174**. To illustrate, the core structure **172** is formed into a tubular shape and surfaces thereof define the plurality of cavities **174**. As illustrative, non-limiting examples, composite materials may be cured to form the core structure **172** or metal may be machined to form the core structure **172**.

The method **1600** also includes, at **1604**, filling the plurality of hexagonal shaped cavities of the honeycomb core structure with foam to generate a foam-filled honeycomb core structure. For example, the foam may include or correspond to the foam **176**, the closed cell foam **134**, or the open cell foam **152** of FIG. **1**. The foam-filled honeycomb core structure may include or correspond to the foam-filled honeycomb core structure **144** of FIG. **1**.

In some implementations, filling **1604** the plurality of hexagonal shaped cavities of the honeycomb core structure with foam includes depositing **1612** the foam in the plurality of hexagonal shaped cavities. To illustrate, the foam **176** is inserted or deposited into the plurality of cavities **174**. In other implementations, filling **1604** the plurality of hexagonal shaped cavities of the honeycomb core structure with foam includes generating **1614** the foam within the plurality of hexagonal shaped cavities. To illustrate, a coating is applied (e.g., sprayed) to the plurality of cavities **174** and heat is applied to the coating to generate or grow the foam **176** in the plurality of cavities **174**.

The method **1600** further includes, at **1606**, coupling an air-impermeable duct wall to an exterior surface of the foam-filled honeycomb core structure. For example, the air-impermeable duct wall may include or correspond to the air-impermeable duct wall **146**, the thermoplastic film **162**, or the rigid tube **166** of FIG. **1**. To illustrate, the air-impermeable duct wall **146** is formed by wrapping the thermoplastic film **162** around the outside or exterior of the foam-filled honeycomb core structure **144**. Alternatively, the air-impermeable duct wall **146** is formed by coupling the rigid tube **166** to the outside or exterior of the foam-filled honeycomb core structure **144**.

In some implementations, the method **1600** further includes coupling **1622** closed a rigid perforated tube of composite material to an interior surface of the foam-filled honeycomb core structure. To illustrate, the rigid perforated tube of composite material is coupled to the interior surface of the foam-filled honeycomb core structure **144**. In other implementations, the method **1600** further includes coupling **1624** closed cell foam to an interior surface of the foam-filled honeycomb core structure. To illustrate, the closed cell foam **134** is coupled to the interior surface of the foam-filled honeycomb core structure **144**.

The method **1400** of FIG. **14**, the method **1500** of FIG. **15**, and/or the method **1600** of FIG. **16** may be initiated or controlled by an application-specific integrated circuit (ASIC), a processing unit, such as a central processing unit (CPU), a controller, another hardware device, a firmware device, a field-programmable gate array (FPGA) device, or any combination thereof. As an example, the method **1400** of FIG. **14** can be initiated or controlled by one or more processors, such as one or more processors included in a control system. In some implementations, a portion of the method **1400** of FIG. **14** may be combined with a second portion of one of the method **1500** of FIG. **15** or the method **1600** of FIG. **16**. Additionally, one or more operations described with reference to FIGS. **14-16** may be optional and/or may be performed in a different order than shown or described. Two or more operations described with reference to FIGS. **14-16** may be performed at least partially concurrently.

Referring to FIGS. **17** and **18**, examples of the disclosure are described in the context of a vehicle manufacturing and service method **1700** as illustrated by the flow chart of FIG. **17** and a vehicle **1802** as illustrated by the block diagram **1800** of FIG. **18**. A vehicle produced by the vehicle manufacturing and service method **1700** of FIG. **17**, such as the vehicle **1802** of FIG. **18**, may include an aircraft, an airship, a rocket, a satellite, a submarine, or another vehicle, as illustrative, non-limiting examples. The vehicle **1802** may be manned or unmanned (e.g., a drone or an unmanned aerial vehicle (UAV)).

Referring to FIG. **17**, a flowchart of an illustrative example of a method of duct manufacturing and service is shown and designated **1700**. During pre-production, the exemplary method **1700** includes, at **1702**, specification and design of a vehicle, such as a vehicle **1802** described with reference to FIG. **18**. During the specification and design of the vehicle **1802**, the method **1700** may include specifying a design of a duct, such as the one or more of the ducts **102**A-**102**C of FIG. **1**. At **1704**, the method **1700** includes material procurement. For example, the method **1700** may include procuring materials for one or more of the ducts **102**A-**102**C of the vehicle **1802**.

During production, the method **1700** includes, at **1706**, component and subassembly manufacturing and, at **1708**, system integration of the vehicle **1802**. The method **1700** may include component and subassembly manufacturing (e.g., manufacturing one or more of the ducts **102**A-**102**C of FIG. **1**) of the vehicle **1802** and system integration (e.g., coupling one or more of the ducts **102**A-**102**C of FIG. **1** to one or more components of the vehicle **1802**, such as components of the ECS **202** of FIG. **2**). At **1710**, the method **1700** includes certification and delivery of the vehicle **1802** and, at **1712**, placing the vehicle **1802** in service. Certification and delivery may include certifying one or more of the ducts **102**A-**102**C of FIG. **1** by inspection or non-destructive testing. While in service by a customer, the vehicle **1802** may be scheduled for routine maintenance and service (which may also include modification, reconfiguration, refurbishment, and so on). At **1714**, the method **1700** includes performing maintenance and service on the vehicle **1802**. The method **1700** may include performing maintenance and service of the ECS **202** of FIG. **2**, such as the duct system **212** or the air conditioning unit **214**, or one or more of the ducts **102**A-**102**C of FIG. **1**. For example, maintenance and service of the duct system **212** may include replacing one or more ducts of the duct system **212** with one or more of the ducts **102**A-**102**C. As a particular non-limiting illustration, performing maintenance and service includes removing a duct and noise attenuating muffler from the ECS **202** and installing one or more of the ducts **102**A-**102**C in the ECS **202** to replace the duct and the noise attenuating muffler (e.g., a zone muffler).

Each of the processes of the method **1700** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of vehicle manufacturers and major-system subcontractors; a third party may include without limitation any number of venders, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

Referring to FIG. **18**, a block diagram **1800** of an illustrative implementation of the vehicle **1802** that includes a duct, such as one or more of the ducts **102**A-**102**C of FIG. **1**. To illustrate, the vehicle **1802** may include an aircraft, such as the aircraft **200** of FIG. **2**, as an illustrative, non-limiting example. The vehicle **1802** may have been produced by at least a portion of the method **1700** of FIG. **17**. As shown in FIG. **18**, the vehicle **1802** (e.g., the aircraft **200** of FIG. **2**) includes an airframe **1818**, an interior **1822**, and a plurality of systems **1820**. The plurality of systems **1820** may include one or more of a propulsion system **1824**, an electrical system **1826**, an environmental system **1828**, or a hydraulic system **1830**. The plurality of systems **1820** further includes the ECS **202**. The ECS **202** may be part of the environmental system **1828** or separate from the environmental system **1828**. The ECS **202** includes the first zone ducts **232**, the riser ducts **234**, the second zone ducts **236**, and one or more of the ducts **102**A-**102**C. The ducts **102**A-**102**C may be manufactured by one or more steps of the methods of FIGS. **14-16**.

Apparatus and methods included herein may be employed during any one or more of the stages of the method **1700** of FIG. **17**. For example, components or subassemblies corresponding to production process **1708** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the vehicle **1802** is in service, at **1712** for example and without limitation. Also, one or more apparatus implementations, method implementations, or a combination thereof may be utilized during the production stages (e.g., stages **1702-1710** of the method **1700**), for example, by substantially expediting assembly of or reducing the cost of the vehicle **1802**. Similarly, one or more of apparatus implementations, method implementations, or a combination thereof, may be utilized while the vehicle **1802** is in service, at **1712** for example and without limitation, to maintenance and service, at **1714**.

FIG. **19** is a diagram **1900** that illustrates a top view of an example of the aircraft **200** including the ECS **202** of FIG. **2**. With reference to FIG. **19**, the aircraft **200** comprises a pair of wings **1904** faired into a fuselage **1902**. Each wing **1904** carries an engine **1906**. The fuselage **1902** comprises the cabin **312** for passengers and crew. In the present embodiment, the aircraft **200** includes two air conditioning units **214** to provide the treated air **352** (i.e., conditioned air) of FIG. **3** to the cabin **312** via the duct system **212**.

In the implementation illustrated in FIG. **19**, each air conditioning unit **214** has a corresponding duct system **212** that extends along a length of the cabin **312** fore and aft. The duct system **212** includes the first zone ducts **232**, the riser ducts **234**, and the second zone ducts **236** of FIG. **2**. One or more of the first zone ducts **232**, the riser ducts **234**, or the second zone ducts **236** include one or more of the ducts **102**A-**102**C. The first zone ducts **232**, the riser ducts **234**, and the second zone ducts **236** can be arranged as illustrated in FIG. **3**. For example, the first zone ducts **232** receive the treated air **352** from a corresponding air conditioning unit **214** and provide the treated air **352** to the outlet ports **238**, such as via the riser ducts **234** and/or the second zone ducts **236**. Although two exemplary outlet ports **238** are illustrated in FIG. **19**, the duct system **212** can include more the two outlet ports **238**.

Each air conditioning unit **214** has or is coupled to at least one exhaust port **224** for outputting waste hot air from the air conditioning unit **214** overboard to atmosphere. In a particular implementation, each exhaust port **224** includes a corresponding ram air outlet (not shown) located on the underside of the corresponding wing **102**.

In the implementation illustrated in FIG. **19**, each air conditioning unit **214** has two intake ports **222** for receiving air to be treated and distributed to the cabin **312** via the duct system **212** and/or waste hot air to be exhausted. In the implementation illustrated in FIG. **19**, each air conditioning unit **214** has an intake port **222**A (e.g., a first intake port) to receive air from the atmosphere and has an intake port **222**B (e.g., a second intake port) to receive air from the cabin **312**.

The illustrations of the examples described herein are intended to provide a general understanding of the structure of the various implementations. The illustrations are not intended to serve as a complete description of all of the elements and features of apparatus and systems that utilize the structures or methods described herein. Many other implementations may be apparent to those of skill in the art upon reviewing the disclosure. Other implementations may be utilized and derived from the disclosure, such that structural and logical substitutions and changes may be made without departing from the scope of the disclosure. For example, method operations may be performed in a different order than shown in the figures or one or more method operations may be omitted. Accordingly, the disclosure and the figures are to be regarded as illustrative rather than restrictive.

Moreover, although specific examples have been illustrated and described herein, it should be appreciated that any subsequent arrangement designed to achieve the same or similar results may be substituted for the specific implementations shown. This disclosure is intended to cover any and all subsequent adaptations or variations of various implementations. Combinations of the above implementations, and other implementations not specifically described herein, will be apparent to those of skill in the art upon reviewing the description.

The Abstract of the Disclosure is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, various features may be grouped together or described in a single implementation for the purpose of streamlining the disclosure. Examples described above illustrate but do not limit the disclosure. It should also be understood that numerous modifications and variations are possible in accordance with the principles of the present disclosure. As the following claims reflect, the claimed subject matter may be directed to less than all of the features of any of the disclosed examples. Accordingly, the scope of the disclosure is defined by the following claims and their equivalents.

What is claimed is:

1. A duct comprising:

a rigid tube of composite material;

an insulation layer disposed within the rigid tube; and

a biasing member disposed within the rigid tube, the biasing member configured to restrain the insulation layer against an interior surface of the rigid tube, wherein the insulation layer is coupled to the biasing member by the biasing member being threaded through the insulation layer.

2. The duct of claim **1**, wherein the biasing member comprises a spring, and wherein the insulation layer comprises open cell foam or aramid felt.

3. The duct of claim **1**, further comprising an adhesive material coupled to coupling the insulation layer to the rigid tube of composite material and configured to restrain the insulation layer, wherein the adhesive material includes adhesive tape, and wherein the adhesive tape includes metallized polyether ether ketone (MPEEK).

4. The duct of claim **1**, further comprising a sleeve coupled to an exterior surface of the rigid tube via an adhesive material, the sleeve configured to overlap a portion of an end of the rigid tube and to overlap a portion of an end of a second duct to couple the duct and the second duct in fluid communication.

5. The duct of claim **1**, further comprising an internal coupler coupled to an interior surface of the rigid tube, the internal coupler configured to overlap a portion of an end of the rigid tube and to overlap a portion of an end of a second duct to couple the duct and the second duct in fluid communication.

6. A vehicle including the duct of claim **1**, the vehicle comprising:

an environmental control system, the environmental control system including:

an air conditioning unit;

first zone ducts;

second zone ducts; and

riser ducts coupled to the first zone ducts and the second zone ducts, wherein one of the first zone ducts, the second zone ducts, or the riser ducts comprises the duct of claim **1**.

7. The vehicle of claim **6**, wherein the first zone ducts do not include a noise attenuating muffler.

8. A method of manufacturing a duct, the method comprising:

inserting insulation into a rigid tube of composite material to form a layer of insulation within the rigid tube, the layer of insulation in contact with an inner surface of the rigid tube; and

inserting a biasing member into the rigid tube of composite material to secure the layer of insulation within the rigid tube, wherein the layer of insulation is coupled to the biasing member by the biasing member being threaded through the layer of insulation.

9. The method of claim **8**, further comprising, prior to inserting the insulation, coupling the insulation to the biasing member, and wherein the insulation and the biasing member are inserted into the rigid tube as a unitary piece.

10. The method of claim **8**, wherein the insulation, the biasing member, or both are inserted into the rigid tube via an inlet of the rigid tube, an outlet of the rigid tube, or both.

11. The duct of claim **1**, wherein the composite material of the rigid tube is non-permeable and forms an air impermeable exterior duct wall.

12. The duct of claim **1**, wherein the biasing member is a helical compression spring.

13. The duct of claim **1**, wherein the insulation layer comprises open cell foam, aramid felt, or high mass fabric, and combinations thereof.

14. The duct of claim **1**, wherein the insulation layer comprises open cell foam, and said open cell foam is melamine foam.

15. The duct of claim **1**, wherein the insulation layer comprises aramid felt, and said aramid felt is aramid fibers, para-aramid fibers, or a combination thereof.

16. The duct of claim **15**, wherein the insulation layer comprises aramid fibers, selected from meta-aramid fibers, para-aramid fibers, or a combination thereof; and wherein said aramid fibers are matted, condensed, and/or pressed together.

17. The duct of claim **16**, wherein the insulation layer comprises meta-aramid fibers.

18. The method of claim **8**, wherein the composite material of the rigid tube is non-permeable and forms an air impermeable exterior duct wall.

19. The method of claim **8**, wherein the biasing member is a helical compression spring.

20. The method of claim **8**, wherein the layer of insulation comprises open cell foam, aramid felt, or high mass fabric, and combinations thereof.

21. The method of claim **8**, wherein the layer of insulation comprises open cell foam, and said open cell foam is melamine foam.

22. The method of claim **8**, wherein the layer of insulation comprises aramid felt, and said aramid felt is aramid fibers, para-aramid fibers, or a combination thereof.

23. The method of claim **22**, wherein the layer of insulation comprises aramid fibers, selected from meta-aramid fibers, para-aramid fibers, or a combination thereof; and wherein said aramid fibers are matted, condensed, and/or pressed together.

24. The method of claim **23**, wherein the layer of insulation comprises meta-aramid fibers.

* * * * *